

EFFECTS OF STYLOSANTHES INTERPLANTING ON MILLET GRAIN YIELD,
HERBAGE YIELD, WATER USE EFFICIENCY, AND YIELDS OF
SUBSEQUENT MILLET CROP

By

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To my daughter,
Cristelle Ahunvin Kouamé

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The integration of forage legumes into the low-input, cereal-based farming system of the Sahel may be the key to sustaining crop and livestock production. Field experiments were conducted during 1989 and 1990 at the ICRISAT Sahelian Center located at Sadoré (13°15'N, 2°18'E) in the Republic of Niger to evaluate the productivity of millet (Pennisetum glaucum [L.] R.Br.)/stylo (Stylosanthes spp.) intercropping and rotation systems. The influence on grain yield, herbage yield and crude protein (CP) concentration, water use efficiency (WUE), and on nitrogen (N) and phosphorus (P) uptake was monitored using two planting strategies (PS1 = millet and stylo sown the same year and PS2 = millet sown into 1-yr pre-established stylo) and seven cropping patterns (pure millet [PM], S. fruticosa [Sf], S. hamata [Sh], MSf

intercropped in alternate 1-row [MSf1R] or alternate 3-row [MSf3R], MSh intercropped in alternate 1-row [MSh1R] or alternate 3-row [MSh3R]). Millet and stylo yields were measured from field-harvested samples with their N and P concentrations determined from subsamples. Extractable soil water was measured biweekly. Land equivalent ratio (LER), WUE, and CP concentration were calculated. Millet yields and nutrient uptake following the different systems were determined.

Intercropping millet and stylo in PS1 reduced millet grain yield by 6% to 30% in the alternate 1-row and up to 60% in the alternate 3-row planting patterns. The combined dry matter (DM) yield of millet and stylo increased little but the CP concentration of DM increased up to 40%. In PS2, intercropped millet grain yield was reduced by 26% to 83% whereas the combined DM yield and CP concentration increased 45% and 125%, respectively, relative to PM. An additional 3 to 5 kg DM per unit water use was produced in intercrops. Little change was observed in the chemical properties of the surface soil. Growing millet in rotation increased grain yield by 7% to 78% in PS1 and 22% to 42% in PS2 with no N input. Yield advantages increased with application of N fertilizer and were greatest when millet followed MSf intercrops. A system was proposed for intercropping millet and stylo for a short term to reduce the need for N fertilization of the following millet crop.

CHAPTER I INTRODUCTION

The Sahel is an extensive land area, 400 to 600 km wide and 6,000 km long, bordering the Sahara desert to the south. This bioclimatic zone extends across six countries of West Africa. In this region, rainfall is low, variable, and undependable (Sivakumar, 1986). Mean minimum and maximum temperatures are 22°C and 36°C, respectively. At Niamey, Niger, the mean annual rainfall has been 560 mm over an 80-year period, and evapotranspiration exceeds rainfall 10 months of the year. By the year 2000, the human population in the Sahel is estimated to grow to more than 50 million with the current annual growth rate of 3% (Africa, 1989).

Soils in the Sahel are inherently low in native fertility, especially nitrogen (N) and phosphorus (P). Bationo et al. (1990) reported that the total N level, available P, and organic matter concentration of Sahelian surface soils range from 74 mg to 226 mg kg⁻¹, 1.7 mg to 7.0 mg kg⁻¹, and 20 g to 50 g kg⁻¹, respectively. The majority of these soils belong to the series Psammentic Paleustalf with 90% to 94% sand, 3% to 5% silt, and 2% to 3% clay. Soil temperature at 1400 h during the seedling establishment period of May to June averages 41°C at 5 cm depth.

Available soil water capacity in the 0 to 30 cm layer is approximatively 70 g to 100 g kg⁻¹. Many studies have concluded that inherent low soil fertility is the major constraint to agriculture in the Sahel (IRAT, 1974; Penning de Vries and Djitéye, 1982; Breman and de Wit, 1983; Mughogho et al., 1985; Fussell et al., 1987).

Agriculture in the Sahel is at a subsistence level. Crops are rainfed and sown at low density with 60- to 150-d growing period. Farmers use little or no chemical fertilizer. Consequently, crop yields are very low. In a village survey, McIntire (1986) found that average millet (Pennisetum glaucum [L.] R.Br.) yield and planting density were 274 kg ha⁻¹ and 5200 pockets ha⁻¹, respectively. A pocket is made up of three to five plants of millet planted at the same site (hole). Sorghum (Sorghum bicolor [L.] Moench.) is the other main cereal crop in the Sahel. Both millet and sorghum serve as staple foods, and surpluses are sold locally for cash. They often are grown in mixture with the grain legumes cowpea (Vigna unguiculata [L.] Walp.) and peanut (Arachis hypogaea L.) (IRAT, 1974; Ahmad, 1986). During the past 25 yr, the millet growing area of Niger has doubled to 3.2 million hectares whereas average yield has dropped by 38% (Annuaire, 1990). The expansion of cultivated land into marginal land has decreased the fallow period and accentuated the degradation of soil fertility (Spencer, 1985). It has, therefore, become increasingly

necessary to develop alternative cropping systems in order to augment agricultural productivity.

Livestock is an important component of Sahelian agriculture. The total number of domestic livestock in the Sahel is estimated at 51 million Tropical Livestock Units (TLU) comprising 62% cattle, 14% sheep (Ovis aries L.), 11% goat (Capra hircus L.), 10% camel (Camelus dromadarius L.), and 3% equine (Equus spp.) (asses, mules, horses) (Le Houérou, 1989). One TLU is the cattle equivalent of 250 kg mature dry zebu (Bos indicus L.) cow kept at maintenance. Animals are utilized in the Sahel for work, milk, and meat. They also provide tools, clothing, transport, traction, and fertilizer in the form of manure and urine. Livestock constitutes an important source of revenue. According to 1989 statistics from Niger, livestock trade ranks second after uranium ore and represents at least 40% of total exports from Niger (Annuaire, 1990). The main feed resources for ruminant livestock are crop residues and natural pastures. There is a large variation in time and space in the quantity, quality, and availability of feed. Animals are underfed during the long dry season resulting in low productivity. First offspring are produced at 4 yr for cattle, and 1 to 1.5 yr for small ruminants (Penning de Vries and Djitéye, 1982). Mortality rates are high in young animals. There is an acute need to increase animal production via improved feeding systems.

Livestock and crop production are closely related in the Sahel. Three levels of interaction have been distinguished based on animal movement, available feed type, and population density (Bremen and de Wit, 1983; McIntire and Debrah, 1987). Where population density is low and natural pastures rather than crop residues are used for feeding, the interaction between livestock and cropping is low. This is referred to as nomadism, which prevails in the northern Sahel. In the intermediate interaction, animal movement is moderate with some use of crop residues for feeding. Animals move out of the cultivated zones northward during the rainy season and come back after crop harvest to graze the harvested fields. This corresponds to the transhumance system of livestock production which is the most important in the Sahel. A high degree of livestock-crop interaction implies no transhumance and high stocking rates, with crop residues providing the main feed source. This occurs in the southern Sahel where farmers and/or herders are sedentary.

In recent years, human population has steadily increased in the Sahel. With its 7 million inhabitants, Niger has about 0.77 TLU per capita (Le Houérou, 1989). The increase in population has caused a high demand for food and a subsequent increase in cultivated areas, decrease in fallow period for soil fertility regeneration, reduction in grazing land, and increase in stocking rate. As a result,

land productivity is diminishing and animals are increasingly dependent on low-quality crop residues. This has created an urgent need for improved Sahelian production systems that will mutually benefit both crop and livestock production. Incorporation of forage legumes into Sahelian farming systems could provide important protein to livestock thereby improving the utilization of the potentially energy-rich (carbohydrates) crop residues. Forage legumes could also improve soil fertility through their N-fixing ability. This could decrease the fallow period requirement and increase crop yields. However, adoption of forage legume by farmers in the Sahel will depend on the demonstration of their productivity and advantage to cereal production. The purposes of this study were to investigate the effects of interplanting Stylosanthes spp. on millet yield, nutrient use efficiency and soil productivity. The first part of this dissertation reports and discusses results of a 2-yr study to evaluate the effects of stylo intercropping on millet yields, nutrient uptake, soil properties, and fodder quality-related characteristics. Residual effects of stylo on subsequent millet yield were investigated under four N treatments. Results and discussion of these studies are offered in the second part of the dissertation.

CHAPTER II
EFFECTS OF STYLOSANTHES INTERCROPPING ON MILLET
GRAIN AND STOVER YIELDS AND FODDER QUALITY

Introduction

Intercropping annual food crops and grain legumes is a widespread practice in farming systems of Sub-Saharan Africa (SSA). This technique maximizes returns to manual labor and minimizes risk in a climatically-uncertain environment (Andrews and Kassam, 1976; Trenbath, 1986). Unlike food crops, intercropping forage legumes with cereals is not common in SSA (Okigbo and Greenland, 1976), probably because forages do not contribute directly to food security (Mohamed-Saleem, 1985). In the Sahel, however, forage legume-cereal intercropping may be an important factor to the sustained productivity of both crop and livestock. Over 51 million TLU in the Sahel rely on low-quality cereal stovers. Feed quality and shortages during the long dry season may be overcome by integrating forage legumes into the cereal-based cropping systems.

Forage legume-cereal intercropping has been shown to increase the quantity and quality of biomass yields compared to cereal monocropping (Nair et al., 1979; Singh, 1988; Chandel et al., 1989; Mandal et al., 1990). Mohamed-Saleem (1985) showed that stylo (Stylosanthes guianensis [Aubl.]

SW.)-sorghum (Sorghum bicolor [L.] Moench) intercropping improved the feeding value of residues. The presence of the legume increased the nutritive value of harvested products due to increased protein yield.

Food production may be increased through enhanced soil fertility due to nitrogen (N) fixation by the legume. The N contribution of the legume to the associated cereal varies with legume species and management. Nnadi and Haque (1988) found that whole-plant N concentration of maize (Zea mays L.) was 10% to 22% higher in maize/vetch (Vicia dasycarpa Ten.) intercrop than maize/lablab (Lablab purpureus [L.] Sweet) intercrop. Similarly, Waghmare and Singh (1984a) reported that the protein yield of sorghum grain and stover was 11% to 12% higher when intercropped with fodder cowpea (Vigna unguiculata [L.] Walp.) than with grain cowpea or greengram (Vigna radiata [L.] Wilczek). The occurrence of N accretion from the legume to the associated non-legume plants during growth has been reported in pasture experiments. Simpson (1975) studied the transfer of N from three temperate legumes under periodic defoliation to cocksfoot (Dactylis glomerata L.) and found that the N status and productivity of the associated grass was related to the capacity of the legume to transfer N directly to the grass. Reynolds (1982) compared seven tropical legumes for N fixation and transfer to tall guinea grass (Panicum maximum Jacq.) and Cori grass (Brachiara miliiformis

[Presl.] Chase) and reported that the annual apparent transfer of fixed-N to the companion grass ranged from 5 kg to 42 kg ha⁻¹. More recently, Mallarino et al. (1990), using the ¹⁵N isotope dilution technique, found that 20% of tall fescue (Festuca arundinacea Schreb.) total N yield derived from the associated white clover (Trifolium repens L.), red clover (Trifolium pratense L.) or birdfoot trefoil (Lotus corniculatus L.) at the first harvest of the seeding year. Similar findings were reported for timothy (Phleum pratense L.) grown in mixture with alfalfa (Medicago sativa L.) (Ta and Faris, 1987) and for reed canarygrass (Phalaris arundinacea L.) associated with alfalfa, red clover, white clover and birdfoot trefoil (Heichel and Henjum, 1991). These authors noted that the amount of N transferred increased with time and progressive cuts and with an increased proportion of legume in the mixture. Conversely, other reports have shown no evidence of a direct N transfer from a legume to an associated grass. Instead, they showed that legume fixed-N benefitted the following cereal crops after decomposition of roots and nodules and some mineralization-immobilization processes in the soil (Henzell and Vallis, 1977; Rowland et al. 1988; John et al. 1989; Izaurrealde et al. 1990; Varvel and Peterson, 1990).

Although forage legume intercropping can increase the quantity and quality of feed available from cropland, yield depressions of the main crop have often been reported.

Nnadi and Haque (1988), working with lablab/maize and lablab/sorghum intercrops, found that the production per unit area varied from 81% to 107% of that found when maize was sole cropped. Shelton and Humphreys (1975a, 1975b) reported a 12% to 19% reduction of upland rice (Oryza sativa L.) yield when intercropped with stylo. A reduction of more than 70% in sorghum grain yield was attributed to intercropping with Stylosanthes spp. (Mohamed-Saleem, 1985).

Yield declines in intercropping systems have been attributed to adverse competitive effects for nutrients, light, and moisture (Reddy and Willey, 1979; Willey, 1979; ILCA, 1989). Some of the yield declines can be minimized by judicious crop management. For example, growing crops with different rooting patterns that explore different soil layers could improve overall water and nutrient use efficiency. Likewise, forage legumes that fix large amounts of N or are adapted to low light intensity are most useful for intercropping. Competition can also be reduced by altering the planting time of the different crop components.

Management to reduce competition depends on plant genotype, planting pattern, and climatic conditions. Nnadi and Haque (1988) found that delaying planting of Trifolium steudneri Schweinf into planted maize reduced stover yield whereas grain yield was unaffected. Simultaneous sowing of millet and cowpea decreased millet yields, but production of the two crops was unaffected if cowpea sowing was delayed by

1 wk (Hulet, 1988). Similarly, Mohamed-Saleem (1986) reported that undersowing S. guianensis (Aubl.) SW. 3 to 6 wk after sorghum minimized grain yield reduction. However, no significant yield decline was observed when Alysicarpus vaginalis (L.) DC, Macroptilium lathyrioides (L.) Urb., and Centrosema pascuorum Mart. ex Benth. (Centurion) were sown on the same day with medium duration sorghum. Chamberlin et al. (1986) concluded that competition between legumes and cereals occurs when conditions are good for the establishment and early growth of the legume. In contrast, Serafini (1985) found that, except in poor rainfall conditions, early sowing of cowpea and millet in alternate rows increased cowpea yield without reducing millet grain yield.

Altering planting density and spatial arrangement of intercrops may also minimize plant competition. Growing sorghum and legumes such as Clitoria ternatea L. and Cajanus cajan (L.) Millsp. in a 50:50 ratio resulted in a 21% reduction in total DM and a 10% reduction in total protein yield compared with a sole sorghum crop (Ayoub, 1986). Mohamed-Saleem (1985) pointed out that plant populations of cereals in intercrops should be as close as possible to those of monocrops to avoid cereal yield reduction. However, Hulet (1985), working with millet/cowpea intercropping systems, reported that grain production was optimum when cowpea and millet were planted in 50:50 and

25:75 ratios in poor and good rainfall environments, respectively.

Forage legume intercropping can improve feeding systems and the performance of animals fed crop residue and natural pasture as a basal diet. Humphreys (1978) showed that the quantity, not the quality, of crude protein (CP) in the ration is of major importance. A minimum of 70 g CP kg⁻¹ (11 g N kg⁻¹ on a DM basis) is necessary to keep animals at a maintenance nutritional level. The average CP concentration of legume hay varies from 100 g to 180 g kg⁻¹ whereas cereal residue protein concentration ranges from 30 g to 60 g kg⁻¹. Forage legumes can, therefore, provide ruminants with enough N to meet maintenance and growth requirements. Kouamé et al. (1991), working with sheep fed millet residue as a basal diet, found that a daily supplement of 500 g of Stylosanthes fruticosa (Retz.) Alston hay increased animal daily gains fourfold over the control (non-supplemented) during a 60- to 70-d feeding period. The substitution of one third of cereal straws with legume hay in sheep diet increased the total DM intake by 31% (Mosi and Butterworth, 1985). It was concluded that the beneficial effect of the legume was due to its provision of fermentable N for rumen microorganisms. If adequate amounts of forage legumes can be produced in intercropping systems, ruminant nutrition, and therefore productivity, could be improved.

As noted by Sanchez (1982), legume-cereal intercropping is highly dependent on prevailing agroecological conditions. Since the productivity of intercropping systems varies with plant genotype, management practices, climate and soil conditions, it is essential to develop technologies appropriate to specific situations. Further, if forage legume intercropping systems are to be adapted to and adopted in the Sahel, where crop and animal productivity is low, a combination that would sustain millet grain yield while providing sufficient protein-rich fodder needs to be considered. The objective of this study was to determine the effects of Stylosanthes intercropping on millet yields and fodder quality-related characteristics.

Materials and Methods

The experiments were conducted during the 1989 and 1990 growing seasons at the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) Sahelian Center (ISC). The ISC is located at Sadoré (13°15'N latitude, 2°18'E longitude) in the Republic of Niger. The well-drained, sandy soil (Siliceous Isohyperthermic Psammentic Paleustalf) of the station is acidic (pH = 5.6 in 1:1 soil:water mixture) and low in native fertility (West et al. 1984). Soil analysis showed that the top 0-15 cm soil layer contains 74 ppm N, 2.3 mg P kg⁻¹, 1.6 g kg⁻¹ organic matter. Long-term yearly rainfall averages 560.0 mm. Rainfall was

623.0 mm in 1989 and 399.5 mm in 1990. During the study period, mean monthly rainfalls, minimum and maximum temperatures, and relative humidity were calculated from daily recordings.

Legumes for the trials were selected for their performance in previous screening evaluations. A local accession of S. fruticosa (Retz.) Alston (ILCA 13860), a perennial highly-persistent forage legume which is tolerant to drought, and S. hamata (L.) Taub. 'Verano' from South America, which behaves as a bi-annual in Niger with an excellent herbage yield potential (ICRISAT, 1987) were used. Seed of S. hamata 'Verano' were obtained from the International Livestock Centre for Africa (ILCA), headquartered in Addis Ababa, Ethiopia, and S. fruticosa seed were harvested locally at ISC. A composite millet (Pennisetum glaucum [L.] R.Br.) cultivar CIVT (Composite Inter-Varietal de Tarna) was used. This improved variety, bred from four parental lines (P3 Kollo, HKP, Guerguera, and Tamangani), has been recommended to farmers of the region since 1976.

Experiments were conducted in a randomized complete block design in 1989 and 1990. There were seven cropping patterns (PG) and two planting strategies (PS). The two planting strategies were: PS1 - millet sown 2 to 3 wk before stylo on newly cleared land; and PS2 - millet replanted on land previously used for PS1 where stylo will regrow from

stubble. For each planting strategy, seven cropping patterns were evaluated. They included:

- 1) pure millet (PM),
- 2) pure S. fruticosa (Sf),
- 3) millet + Sf in alternate single rows (MSf1R),
- 4) millet + Sf in alternate triple rows (MSf3R),
- 5) pure S. hamata (Sh),
- 6) millet + Sh in alternate single rows (MSh1R),
- 7) millet + Sh in alternate triple rows (MSh3R).

Treatment combinations were replicated fourfold and arranged as a split-split plot in time. Year was assigned to main plots, planting strategy to subplots, and cropping pattern randomly to sub-subplots of 9 by 12 m. Each plot received an annual application of 13 kg P ha⁻¹ as single superphosphate which was broadcast preplant and incorporated into 40- to 50-cm tall ridges with an oxen-drawn plough after the first rains. At approximately 30 d post emergence millet was top-dressed with 15 kg N ha⁻¹ (land area basis) as calcium ammonium nitrate in a single application.

Millet was sown in pockets at 1.2-m spacing on ridges 0.75-m apart on 30 June 1989 and 30 May 1990. Planting consisted of dropping 10-20 seeds into a 4- to 5-cm deep hole made with a hoe and stepping on it to cover the seed. Millet plants were thinned 3 wk later to three per individual planting site. Those three plants are referred

to as a pocket. Millet planting densities were 11,000 and 5,500 pockets ha⁻¹ (33,000 and 16,500 plants ha⁻¹), respectively, in sole and intercrop treatments. The plots were hand weeded twice during each growing season using a locally made implement (Iler) which cut weeds at 2 to 3 cm depth and left them on the soil surface. Millet was harvested on 3 Oct. 1989 and 7 Sep. 1990. The stylo lines were sown in continuous rows on firm ridges, 0.75-m apart, and remained unthinned. Stylo seed was properly inoculated with a mixture of Rhizobium strains obtained from ILCA (cowpea type) and the University of Hawaii NIFTAL project (stylo type and Macroptiloma type). Stylo plantings occurred on 12 July 1989 and 25 June 1990 in PS1 and stylo herbage was harvested only once, at the end of the cropping season. In PS2, stylo regrowth was harvested twice, approximately 60 and 120 d after millet emergence. All stylo plants were cut at a 15-cm stubble with a locally made hand-sickle.

Yields were measured by hand-harvesting and weighing the biomass from the innermost 3 by 6 m of each subplot. Millet plants were fractionated into panicles, leaf (blade plus sheath), and stem. Subsamples of millet plant parts were sun-dried to constant weight for dry matter (DM) determination. Panicles were threshed to determine grain yield. Subsamples of stylo herbage were oven dried (75°C, 48h) for DM determination. Seed yield was determined at the

second harvest of PS2 only. All plant samples were milled to pass through a 1-mm screen, and acid-digested using a modification of the aluminum block digestion procedure (Gallaher et al. 1975) with N and phosphorus (P) determined, after distillation, respectively by titration and semi-automated colorimetry (Hambleton, 1977). Crude protein yield was calculated by multiplying N yield by 6.25. Relative DM yields (RY) of each intercrop component and land equivalent ratio (LER) of the intercrops were calculated. Relative yield is defined as the yield ratio of an intercropped species per unit area of intercropped land to the yield per unit area of the same species in monoculture. The summation of the RY over the interplanted species gives the LER ($LER = RY_i + RY_j$; with i, j =intercropped species).

Analysis of variance using the general linear model procedures (SAS Institute, 1982) was used to determine treatment effects on yields of millet grain and stover components, stylo herbage and seed yield, and nutrient uptakes. Differences in treatment means were separated using single-degree-of-freedom orthogonal contrasts.

Results and Discussion

Yields of millet and stylo were highly affected by planting strategy by year interaction (Table 2.1) as a result of yearly differences in rainfall (Fig. 1). May to October rainfalls was 11% higher in 1989 and 29% lower in

Table 2.1. Probability levels (F-test) for year, planting strategy (PS), cropping pattern (CR), and interaction effects on millet and stylo yields.

Source	Millet		Stylo Herbage	Total Dry Matter
	Grain	Stover		
Year	0.22	0.86	0.01	0.19
Planting strategy (PS)	0.04	0.09	0.01	0.01
Year X PS	0.01	0.01	0.01	0.01
Cropping pattern (CR)	0.01	0.01	0.01	0.01
CR X PS	0.19	0.01	0.01	0.01
Year X CR	0.01	0.27	0.01	0.01
Year X PS X CR	0.01	0.49	0.01	0.01
CV %	30	32	22	20

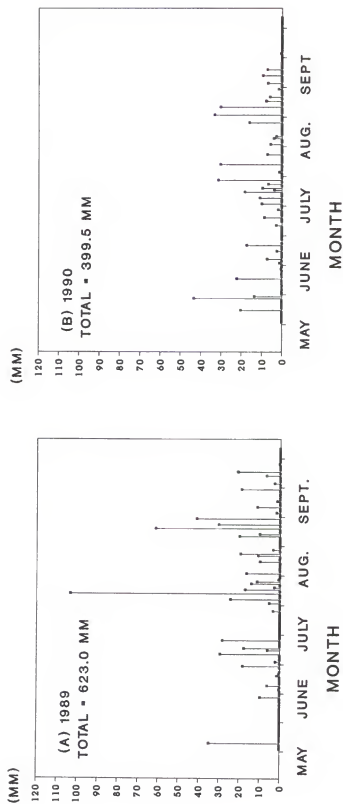


Figure 1. Daily rainfall at the experimental station in 1989 and 1990.

1990 than the long-term annual mean of 560 mm. During 1989, more than 40% of the precipitation fell during the month of August, and occurrences of drought were frequent during the crop establishment period. This resulted in seedling death and the need to replant, with late sowing resulting in reduced yield. On the other hand, crops were established early in the 1990 growing season and rainfall was more evenly distributed with drought periods occurring only near the end of the season (Fig. 1).

Millet yield in the Sahel is determined more by rain onset and the period of planting than by total precipitation (Sivakumar, 1988). The author also found a high correlation between date of rain onset and growing season length. Early establishment of crops with the first substantial rains maximizes grain production in most years (Andrews and Kassam, 1976; Fussell et al. 1987). Given the important year-to-year climatic variation in this research and the significant second and third level interactions involving Year, PS, and PG, data were analyzed and presented according to planting strategy on a yearly basis.

Planting Strategy I

During the stylo seeding year, PM grain yields were higher ($P < 0.01$) in 1989 than those of intercrop millet (Table 2.2a) and there was a trend ($P = 0.13$) for PM to exceed intercrop in 1990. Alternate triple-row planting patterns

Table 2.2. Millet and stylo yields as affected by cropping pattern in planting strategy I.

A. Millet

Cropping pattern†	--- 1989 ---		--- 1990 ---	
	Grain	Stover	Grain	Stover
	----- Mg ha ⁻¹ -----			
Pure millet	1.08	2.70	0.59	1.96
Intercrop MSf1R	0.80	2.40	0.54	1.48
Intercrop MSf3R	0.61	2.40	0.41	1.35
Intercrop MSh1R	1.02	2.43	0.41	1.45
Intercrop MSh3R	0.44	1.27	0.34	0.94
CV %	30	34	37	17
Contrast‡				
Millet vs intercrop	0.01	0.20	0.13	0.03
Intercrop 1R vs 3R	0.15	0.15	0.27	0.12
Intercrop MSf vs MSh	0.28	0.17	0.36	0.21

B. Stylo

Cropping pattern†	----- 1989 -----		----- 1990 -----	
	fruticosa	hamata	fruticosa	hamata
	----- kg ha ⁻¹ -----			
Pure stylo	210	550	780	130
Intercrop 1R	20	20	200	50
Intercrop 3R	330	330	400	60
CV %	37	30	42	20
Contrast‡				
Stylo vs intercrop	0.35	0.01	0.08	0.04
Intercrop 1R vs 3R	0.01	0.01	0.32	0.56

† Cropping pattern abbreviations: M=millet, Sf=Stylosanthes fruticosa, Sh=S. hamata, 1R=Alternate single-row planting arrangement, 3R=Alternate triple-row planting arrangement.

‡ Probability levels (F-test) for single-degree-of-freedom orthogonal contrast.

appeared to decrease millet grain yield more than the alternate single-row planting ($P=0.15$ in 1989 and $P=0.27$ in 1990). Pure millet stover yield was higher ($P=0.03$) in 1990 and numerically greater ($P=0.20$) in 1989 than that of intercrop millet. Stover yields were generally higher ($P=0.15$ and 0.12 in 1989 and 1990, respectively) in the alternate single-row than in the alternate triple-row planting. Millet planted in alternate triple-row with S. hamata tended to yield the lowest stover biomass in both years, averaging a 52% reduction from PM. Low intercrop millet grain and stover yields was likely due to the reduced millet plant population in the intercrop treatments compared to PM. This is consistent with the substitutive theory proposed by Willey (1979). In our study, substituting 50% of the millet plants with stylo in the intercrop led to the reduction in the yield of intercropped millet.

The spatial arrangement (wide spacing between rows) of millet plants in the alternate single-row treatment could explain the yield superiority tendency over alternate triple-row. Azam-Ali et al. (1984) studied the growth and development of millet at various spacings and found that yield was greater in the wide-spacing (1.50 m) than in the narrow-spacing (0.38 m) treatment. At 1.50 m spacing, the plants were highly prolific, producing large amount of assimilate due to little mutual shading. In our investigation, the alternate single-row plants were widely

spaced (1.50 m between rows) and were likely to have little interplant competition unlike plants in the alternate triple-row treatments.

The herbage yield of seeded stylo varied with the cropping pattern. Stylo herbage yields were higher in pure stands ($P < 0.01$ and $P = 0.04$ in 1989 and 1990 for Sh, and $P = 0.08$ for Sf in 1990) than those of intercrop, except in 1989 when S. fruticosa herbage was higher in intercrop than Sf due to poor establishment (Table 2.2b). Alternate triple-row planted stylo herbage yield was greater ($P < 0.01$ for both Sf and Sh) in 1989 and greater but not different than alternate single-row intercrops in 1990. Intercropped stylo herbage yield in alternate single-row was about 93% less in 1989 than yields obtained in alternate triple-row planting. When averaged over cropping patterns, S. hamata herbage yield was 1.6 times greater than that of S. fruticosa in 1989. In 1990, however, S. fruticosa herbage yield was 5.8 times greater than S. hamata yield. These contrasting trends could be partly related to seed properties. Seeds were scarified in 1990 but not in 1989, and germination of S. fruticosa was slower than that of S. hamata in 1989 due to hardseedness (Kouamé, unpublished). The tendency for higher millet yield in the alternate single-row planting treatments compared to alternate triple-row partly accounts for the low stylo herbage yield in the alternate single treatments. A negative correlation between

the DM yield of rice and the companion undersown S. guianensis was reported in Asia (Shelton and Humphreys, 1975a). A poor yield of S. hamata 'Verano' intercropped with maize was ascribed to a shading effect of the cereal canopy (McCown et al., 1985). Namibiar et al. (1983) working, with intercrop groundnut (Arachis hypogaea L.)/maize, groundnut/millet, and groundnut/sorghum, reported a decrease in the photosynthetic activity of the legume canopy due to shading, reducing groundnut yields. Although no light measurements were taken in this research, alternate single-row planting is likely to shade stylo seedlings, causing greater yield decline of the legume than alternate triple-row planting.

The stover yield of PM plots was higher ($P=0.02$) than the combined dry matter (DM) yields of intercropped millet and stylo in 1990 (Table 2.3), and there was a similar trend ($P=0.27$) in 1989. No difference was found between alternate single-row and triple-row intercropping patterns during either year. Intercrop millet/S. fruticosa DM yields were higher ($P=0.05$ in 1990 and $p=0.11$ in 1989) than those of intercrop MSh. Low stylo herbage yields during the seeding year contributed very little to intercrop total DM, leading to no yield advantage of intercropping over millet monoculture. Relative DM yields (RY) showed that millet was the dominant crop (RY millet > RY stylo) when planted in alternate single-row with stylo during both study years.

Table 2.3. Total dry matter (DM) and crude protein (CP) yields of millet and stylo in planting strategy I.

Cropping pattern [†]	---- 1989 ----			---- 1990 ----		
	DM	CP		DM	CP	
	----- kg ha ⁻¹ -----					
Pure millet	2700	117	(43)	1960	96	(48) [‡]
Intercrop MSf1R	2420	140	(58)	1580	89	(56)
Intercrop MSf3R	2720	172	(63)	1740	129	(75)
Intercrop MSh1R	2450	129	(53)	1480	89	(59)
Intercrop MSh3R	1630	98	(60)	1000	40	(41)
Pure <u>S. fruticosa</u>	210	25	(119)	780	96	(123)
Pure <u>S. hamata</u>	550	68	(124)	120	15	(127)
CV %	35	41	16	21	18	13
Contrast [*]						
Millet vs intercrop	0.27	0.49	0.03	0.02	0.17	0.33
Intercrop 1R vs 3R	0.43	0.98	0.39	0.44	0.98	0.74
Intercrop MSf vs MSh	0.11	0.06	0.71	0.03	0.01	0.03
Stylo vs intercrop	0.01	0.01	0.01	0.01	0.01	0.01

[†] Cropping pattern abbreviations: M=millet, Sf=Stylosanthes fruticosa, Sh=S. hamata, 1R=Alternate single-row planting arrangement, 3R=Alternate triple-row planting arrangement.

[‡] Number in parentheses is CP concentration (g CP kg⁻¹ DM⁻¹).

^{*} Probability levels (F-test) for single-degree-of-freedom orthogonal contrast.

With the exception of MSf3R in 1989, LER of intercrop treatment ranged from 0.94 to 1.07 in 1989, and 0.96 to 1.19 in 1990, indicating little or no DM yield advantage of intercropping in planting strategy I.

Although stylo intercropping reduced yields in some treatments, the crude protein (CP) concentration of intercrop total DM was greater ($P=0.03$) in 1989 and tended to be greater in 1990 than that of PM (Table 2.3). Except for MSh3R, CP increased by 4% to 56% in intercrop compared to PM. Nonetheless, CP concentration of all harvested DM was generally well below 70 g CP kg⁻¹, the reported critical maintenance level for ruminants. The only treatment to exceed 70 g CP kg⁻¹ DM⁻¹ was alternate triple-row planted MSf in 1990. This poor feeding quality was likely due to the small contribution of protein-rich stylo in the total DM yield.

Planting Strategy II

In the second planting strategy, PM produced higher ($P<0.01$) grain and stover yields in both years than when intercropped with stylo (Table 2.4). Relative to PM, grain yield of intercrop millet was reduced by 26 to 83%. Cropping patterns involving S. hamata reduced millet grain ($P<0.01$) and stover ($P=0.04$) yields more than those involving S. fruticosa in 1990 but not in 1989. Alternate single-row planting of millet with either stylo yielded, on

Table 2.4. Millet yield as affected by cropping pattern in planting strategy II.

Cropping pattern [†]	---- 1989 ----		----- 1990 ----	
	Grain	Stover	Grain	Stover
	----- Mg ha ⁻¹ -----			
Pure millet	0.64	2.66	0.83	3.20
Intercrop MSf1R	0.31	1.21	0.43	2.23
Intercrop MSf3R	0.11	0.62	0.61	1.84
Intercrop MSh1R	0.27	1.00	0.22	1.28
Intercrop MSh3R	0.14	0.81	0.44	1.31
CV %	39	42	14	28
Contrast [‡]				
Millet vs intercrop	0.01	0.01	0.01	0.01
Intercrop 1R vs 3R	0.02	0.27	0.01	0.86
Intercrop MSf vs MSh	0.44	0.76	0.01	0.04

[†] Cropping pattern abbreviations: M=millet, Sf=Stylosanthes fruticosa, Sh=S. hamata, 1R=Alternate single-row planting arrangement, 3R=Alternate triple-row planting arrangement.

[‡] Probability levels (F-test) for single-degree-of-freedom orthogonal contrast.

average, 1.4 times more grain ($P=0.02$) than alternate triple-row planting in 1989 whereas the latter planting system outyielded the former by 62% in 1990 ($P<0.01$). Millet stover yield was, on average, 56% higher when intercropped with Sf than with Sh in 1990. The contrasting trends in millet grain yields may be related to the different rainfall pattern during 1989 and 1990 growing seasons. A drought period near the end of the 1990 growing season caused a moisture stress to the millet plants in alternate single-row treatment. Moisture stress was more severe in MSh than in MSf plots (visual observations) likely due to dense Sh root systems in the upper soil profile. The alternate single-row arrangement of millet and stylo likely increased competition for moisture between millet and stylo more than in the alternate triple-row arrangement. These may have resulted in a higher millet grain yield reduction in the single-row than in the triple-row intercrops and a higher millet grain and stover yields in MSf than in MSh intercrops in 1990.

Cereal yield reductions due to intercropping with grain and fodder legumes have been reported. In the Sahel of West Africa, N'tare (1989) found reductions in millet grain of 24 to 54% when intercropped in a 50:50 ratio with cowpea from various maturity groups. Reduction of 11 to 73% was reported in rice grain yield in India when rice was intercropped with mungbean (Vigna radiata L.), ricebean

(Vigna umbellata L.), blackgram (Vigna mungo [L.] Hepper) peanut, and soybean (Mandal et al. 1990). These authors stated that the higher the proportion of the cereal in the intercrop system, the lower the grain yield reduction. Similar results were obtained with maize/fodder cowpea and forage maize/stylo and sorghum/stylo intercrops (Mohamed-Saleem, 1985; Kamara and Haque, 1991). In our experimental plots, reducing millet plant populations to achieve single and triple rows of stylo partly explains the large yield decline due to intercropping. In addition, plant height measured at 60 d post emergence in 1990 showed that intercrop millet growth was reduced ($P < 0.01$) compared to PM. Millet plants were shorter ($P = 0.02$) in MSh than in MSf intercrops. Relative DM yields indicated that regrowing stylo, unlike seeded stylo, was very aggressive (RY stylo > RY millet), which may well have contributed to reduced intercrop millet growth and yields.

Monocultured production of S. fruticosa resulted in higher herbage ($P = 0.02$ and $P < 0.01$) and seed ($P = 0.03$ and $P < 0.01$) yields than intercropped culture in 1989 and 1990, respectively (Table 2.5a,b). Similarly, monoculture herbage and seed yields of S. hamata were higher ($P < 0.01$ and $P = 0.03$) than those of intercrops in 1990. In 1989, Sh herbage and seed yields were higher ($P < 0.01$ and $P = 0.08$, respectively) in intercrop than monocrop due to poor regrowth caused by plants being cut too short the previous year. Monoculture

Table 2.5. Stylo herbage and seed yields as affected by cropping pattern in planting strategy II.

A. Herbage yield				
Cropping pattern†	----- 1989 -----		----- 1990 -----	
	fruticosa	hamata	fruticosa	hamata
	----- kg ha ⁻¹ -----			
Pure stylo	3070	1260	2890	3940
Intercrop 1R	2030	4700	1520	3060
Intercrop 3R	2510	4120	1150	2270
CV %	15	20	13	7
Contrast‡				
Stylo vs intercrop	0.02	0.01	0.01	0.01
Intercrop 1R vs 3R	0.08	0.30	0.08	0.01

B. Seed yield				
Pure stylo	230	10	80	10
Intercrop 1R	160	40	60	0
Intercrop 3R	150	20	10	0
CV %	27	17	29	29
Contrast‡				
Stylo vs intercrop	0.03	0.08	0.01	0.03
Intercrop 1R vs 3R	0.78	0.02	0.01	0.86

† Cropping pattern abbreviations: M=millet, Sf=Stylosanthes fruticosa, Sh=S. hamata, 1R=Alternate single-row planting arrangement, 3R=Alternate triple-row planting arrangement.

‡ Probability levels (F-test) for single-degree-of-freedom orthogonal contrast.

yield superiority appeared to be the result of higher plant population in the monocrops. Pure stylo plots had two times more plants than both single and triple-row intercrops. Alternate single-row planting of S. hamata produced more herbage than alternate triple-row planting in 1990 ($P < 0.01$) and tended in the same direction in 1989. In contrast, alternate single-row planted Sf herbage yield was lower ($P = 0.08$) in 1989 and higher ($P = 0.08$) in 1990 than alternate triple-row planted Sf. Seed yields of the two stylo species were numerically greater in alternate single-row than alternate triple row. The higher performance of single-row treatments could be due to the wide row spacings which allows the plant to produce more herbage and seed as compared to triple-row plantings. That no seed was harvested in intercropped MSh in 1990 was due to the short growing period dictated by rainfall. The variation observed treatments involving Sf could be due to change of rainfall regime over years which affected the associated millet yield. When averaged over cropping patterns, the two stylo species tended to differ in their seed and DM production abilities, with S. hamata producing two times more herbage and 4.5 times less seed than S. fruticosa.

Pure millet leaf, stem, and grain N concentrations were not different from concentrations of N in the intercrops in either year (Table 2.6a). This is consistent with Nnadi and Haque (1988) findings that intercropping did not affect N

Table 2.6. Nitrogen (N) and phosphorous (P) concentrations of millet as affected by cropping pattern in planting strategy II.

A. N concentration

Cropping pattern [†]	----- 1989 -----			----- 1990 -----		
	Leaf	Stem	Grain	Leaf	Stem	Grain
	----- g kg ⁻¹ -----					
Pure millet	13.1	6.9	19.6	8.3	3.0	17.9
Intercrop MSf1R	13.0	5.3	19.1	9.1	3.9	19.0
Intercrop MSf3R	12.9	6.7	20.8	7.5	2.1	16.4
Intercrop MSh1R	11.8	6.2	21.5	10.5	3.8	22.7
Intercrop MSh3R	13.7	6.3	18.8	7.0	2.0	15.2
CV %	8	42	16	19	34	8
Contrast [‡]						
Millet vs Intercrop	0.89	0.96	0.79	0.82	0.98	0.63
Intercrop 1R vs 3R	0.19	0.76	0.85	0.01	0.01	0.01
Intercrop MSf vs MSh	0.77	0.96	0.81	0.65	0.92	0.11

B. P concentration

Pure millet	1.47	1.15	2.91	0.69	0.32	2.72
Intercrop MSf1R	1.48	0.95	3.62	0.79	0.29	2.87
Intercrop MSf3R	1.49	1.19	3.72	0.72	0.30	2.67
Intercrop MSh1R	1.50	0.81	3.62	1.07	0.67	3.77
Intercrop MSh3R	1.95	1.37	3.52	1.06	0.50	2.78
CV %	7	25	4	35	72	14
Contrast [‡]						
Millet vs Intercrop	0.13	0.91	0.01	0.23	0.50	0.23
Intercrop 1R vs 3R	0.01	0.02	0.99	0.76	0.58	0.02
Intercrop MSf vs MSh	0.01	0.95	0.42	0.06	0.08	0.03

[†] Cropping pattern abbreviations: M=millet, Sf=*Stylosanthes fruticosa*, Sh=*S. hamata*, 1R=Alternate single-row planting arrangement, 3R=Alternate triple-row planting arrangement.

[‡] Probability levels (F-test) for single-degree-of-freedom orthogonal contrast.

concentration of maize. Concentrations of N in millet plant fractions were, however, higher ($P < 0.01$) in alternate single-row intercrops than in alternate triple-row in 1990. No difference due to stylo species was found in intercropped millet N concentrations in either year. High N concentration in alternate single-row planted millet could be associated with low grain and stover yields of MSh1R in 1990. As a result of less dilution in low DM yield, N concentration was high in all millet plant fractions which, when averaged over planting patterns, yielded a greater mean in the alternate single- than triple-row.

Phosphorus concentration of millet leaf and stem was unaffected by intercropping (Table 2.6b). Millet grain P concentration was higher ($P < 0.01$) in intercrop than monocrop in 1989 probably due to low grain yield of intercropped millet. In 1990, millet grain P was lower ($P = 0.02$) in alternate single-row planting than alternate triple-row planting and higher ($P = 0.03$) in MSh than MSf cropping patterns. Phosphorus concentration of millet leaf ($P < 0.01$) and stem ($P = 0.02$) was higher in alternate single-row than alternate triple-row intercrop in 1989. When intercropped with Sh, millet leaf and stem P concentrations generally were higher than that of MSf intercrop, except for stem P in 1989 when there was no difference. The higher P concentrations of millet leaf, stem, and grain in MSh than MSf intercrop could, perhaps, have been due to less dilution

in low stover and grain yields of MSH intercrops. Contrasting effect of intercropping on nutrient concentrations of cereal has been reported elsewhere. By undersowing rice with stylo, Shelton and Humphreys (1975b) found that rice P concentration was reduced whereas N concentration was not affected by the stylo. Similar to our result with millet, Nnadi and Haque (1988) did not find any difference due to intercropping in maize fodder N concentration.

Nitrogen and P concentrations in leaf and stem of the two stylo species at the time of the first cutting were unaffected by intercropping, except *S. fruticosa* leaf P in 1990 which showed a higher ($P=0.02$) value in monoculture than when intercropped (data not shown). At the second cutting, the herbage N concentration of intercropped Sf was greater ($P=0.03$) in 1990 and tended to be higher ($P=0.13$) in 1989 than that of pure Sf (Table 2.7a). Conversely, the herbage N concentration of pure Sh was greater ($P<0.01$) in 1990 and tended to be greater ($P=0.30$) in 1989 than that of intercropped Sh. Phosphorus concentration of the two stylo species was higher ($P=0.02$) in monocrop than intercrop in 1990 only (Table 2.7b). Across cropping patterns, N concentration of the two legumes were similar, varying from 16.4 to 19.8 g N kg⁻¹ DM for Sf and from 16.9 to 19.3 g N kg⁻¹ DM for Sh. Concentrations of P in both stylo species were low, ranging from 0.50 to 1.36 g P kg⁻¹ DM, with highest and

Table 2.7. Nitrogen (N) and phosphorous (P) concentrations of above-ground stylo dry matter as affected by cropping pattern in planting strategy II (second harvest).

A. N Concentration

Cropping pattern†	----- 1989 -----		----- 1990 -----	
	fruticosa	hamata	fruticosa	hamata
	----- g kg ⁻¹ -----			
Pure stylo	16.4	19.3	17.5	19.3
Intercrop 1R	17.5	18.2	19.8	16.9
Intercrop 3R	17.8	18.5	17.8	18.5
CV %	6	9	3	2
Contrast‡				
Stylo vs intercrop	0.13	0.30	0.03	0.01
Intercrop 1R vs 3R	0.51	0.83	0.52	0.11

B. P concentration

Pure stylo	1.01	1.36	1.09	1.01
Intercrop 1R	1.19	1.22	0.83	0.49
Intercrop 3R	1.25	1.33	1.00	0.89
CV %	22	4	11	27
Contrast‡				
Stylo vs intercrop	0.25	0.13	0.02	0.02
Intercrop 1R vs 3R	0.77	0.04	0.29	0.48

† Cropping pattern abbreviations: M=millet, Sf=Stylosanthes fruticosa, Sh=S. hamata, 1R=Alternate single-row planting arrangement, 3R=Alternate triple-row planting arrangement.

‡ Probability levels (F-test) for single-degree-of-freedom orthogonal contrast.

lowest values occurring in treatments involving Sh. The low P concentration suggested a low internal P requirement by the two legumes. The low N concentration of intercropped Sh could be due to reduced light in intercrop as compared to monocrop. Shading has been reported to reduce plant photosynthetic activity, nodulation, and leaf-to-stem ratio (Namibiari et al. 1983; McCown et al., 1985) which are likely to reduce N concentration of whole plant. That nutrient concentration of total herbage Sf increased with intercropping indicated that Sf, perhaps, has a different shading threshold than Sh.

The combined DM yield of intercropped millet and stylo was greater ($P < 0.01$ in 1989 and $P = 0.07$ in 1990) than that of PM (Table 2.8). Dry matter yield was higher ($P < 0.01$) in alternate single-row than alternate triple-row intercrop in 1990 but not in 1989, likely due to low stylo yield in alternate triple-row treatments. Based on land equivalent ratio (LER), alternate single-row planting systems showed a 12% to 22% intercropping advantage for DM production. Due to high Sh herbage yield, intercrop MSh produced greater ($P < 0.01$) DM than intercrop MSf in either year. Like DM yield, CP yields were higher ($P < 0.01$) in intercrop than PM, higher ($P < 0.01$) in alternate single-row than alternate triple row, and higher ($P < 0.01$) in MSh than MSf intercrops during both study years. The increased yields of intercropped CP and P were mediated through the increased

Table 2.8. Total dry matter (DM), phosphorus (P), and crude protein (CP) yields of millet and stylo in planting strategy II.

Cropping pattern†	1989		1990	
	DM	P	DM	CP
	kg ha ⁻¹			
Pure millet	2660	3.5	158.0 (60)*	3200 1.5 94 (29)
Intercrop MSf1R	3240	4.4	296.4 (94)	3750 3.0 273 (73)
Intercrop MSf3R	3120	5.4	349.4 (111)	3000 2.9 188 (64)
Intercrop MSh1R	5700	8.0	616.1 (107)	4350 4.4 413 (95)
Intercrop MSh3R	4940	7.9	554.6 (113)	3580 3.9 304 (85)
Pure <u>S. fruticosa</u>	3070	5.1	394.9 (119)	2890 4.9 352 (122)
Pure <u>S. hamata</u>	1260	1.5	141.4 (121)	3940 5.3 506 (128)
CV %	17	19	19	10 8 11 10
Contrast‡				
Millet vs intercrop	0.01	0.01	0.01	0.07 0.01 0.01 0.01
Intercrop 1R vs 3R	0.27	0.42	0.91 0.09	0.01 0.38 0.01 0.04
Intercrop MSf vs MSh	0.01	0.09	0.01 0.22	0.01 0.01 0.01 0.01
Stylo vs intercrop	0.01	0.01	0.01 0.02	0.30 0.01 0.01 0.01

† Cropping pattern abbreviations: M=millet, Sf=Stylosanthes fruticosa, Sh=S. hamata, 1R=Alternate single-row planting arrangement, 3R=Alternate triple-row planting arrangement.

* Number in parentheses is CP concentration (g CP kg⁻¹ DM⁻¹).

‡ Probability levels (F-test) for single-degree-of-freedom orthogonal contrast.

percentage of stylo in the total DM yield. That led to a greater ($P<0.01$) CP concentration in intercrop than PM in either year. Similar to DM and CP, P yield was higher ($P<0.01$) in intercrop than PM in either year and higher ($P=0.09$ in 1989 and $P<0.01$ in 1990) in MSh than MSf intercrop. In 1990, the two stylo species produced on average, as much DM as intercrop, higher P ($P<0.01$), and higher CP ($P<0.01$) than intercrop.

Kamara and Haque (1991) recently intercropped maize and fodder cowpea in the highland of Ethiopia and obtained 85% to 143% (i.e. 60 g to 100 g CP kg⁻¹ DM⁻¹) more protein from intercrop than from the pure maize crop residue. Increase of 10 g CP kg⁻¹ DM⁻¹ was also reported in Australia for maize/lablab and oats/field peas intercrops (Mason and Pritchard, 1987). Our data clearly indicated that we raised the total residue protein in 1989 from 60 g CP kg⁻¹ DM⁻¹ in PM to over 100 g CP kg⁻¹ DM⁻¹ in intercrop. Crude protein concentrations in 1990 were also raised from 30 g CP kg⁻¹ DM⁻¹ in PM to 90 g CP kg⁻¹ DM⁻¹ in the intercrop. The increases were proportional to stylo herbage yield in the intercrops. This increase in the nutritive value of harvested crop residues by 69% to 127% through intercropping may provide high levels of protein supplementation to animals feeding on low quality millet crop residues.

Phosphorus is another yield-limiting nutrient in the Sahel. While P deficiency has been reported frequently in

the literature, little has been said about P requirement for domestic grazing animals in the Sahel. It can be seen from our investigation that intercropping millet and stylo increased P uptake of total plant DM on average by 15% in 1989 and 125% in 1990 from their respective value in PM. The concentration of 15 g P kg⁻¹ DM⁻¹ obtained in intercrop was, on average, above the reported 12 g kg⁻¹ DM⁻¹ value found as sufficient for meeting growth requirement of livestock in tropical Australia (Little, 1980), but below the reported 18 g to 43 g kg⁻¹ DM⁻¹ in America (McDowell et al., 1978).

Conclusion

The principle objectives of crop-livestock farmers in the Sahel are to produce primarily enough grain for their family and secondarily enough crop residues for their domestic animals which, in turn, provide milk, meat, and other products to the household. Natural pastures constitute the other important feed source of the livestock. However, the increasing population pressure in recent years has caused an expansion of the cultivated areas at the expense of grazing lands and a depletion of soil fertility. This has resulted in a decline of crop and animal productivity. A technology that would provide sufficient food and feed may limit the degradation of the environment.

Intercropping increases the total output but reduce the yield of the individual crop components (Willey, 1979) due

to reduction of density (substitutive effects) and/or competition for light and soil resources. In our study, reducing millet and stylo densities to achieve a 50:50 planting ratio in intercrop led to a reduction of millet grain yield and an increased of the total herbage dry matter (DM).

In PS1, intercropped millet grain yield declines averaged 6% to 30% in the alternate single-row planting pattern. Grain yield reduction were greater when planted in the alternate triple-row pattern. Herbage yield of intercropped stylo was so low that it contributed little to the total harvested biomass, leading to no DM yield advantage. Although total crude protein yield of intercrop biomass increased, it remained under the critical level of 70 g CP kg⁻¹ DM⁻¹.

With grain yield reduction of 8% to 16% in MSf1R and 6% to 30% MSh1R in 1989 and 1990, respectively, PS1 may meet the farmers' primary need to assure the grain supply of the family. Mohamed-Saleem (1985) reported that a yield reduction of 15% was the maximum acceptable risk for the farmer. However, studies in Burkina Faso showed that a typical family of 5.5 persons living on a 4 ha millet farm consumed 70% of their production. The remaining was marketed (25%), kept for seed (2%), or spoiled (3%) [Kiekens, 1984 (cited by Le Houérou, 1989)]. This indicates that yield loss of up to 25% may not threaten the food

security of the household. Such a risk would be worth taking provided the drop in grain yield brings other benefits equivalent to the income generated by the sale of the grain surplus. In the study by Kiekens (Le Houérou, 1989) the average grain yield of millet was 400 kg ha^{-1} . Over 2 yr, intercropped millet grain yield in our study averaged 700 kg ha^{-1} in the alternate-single row arrangement of PS1 using only half of the N fertilizer required for pure millet. Although the locations were different and despite the fertilizer input in our experiment, there is an indication that a similar typical family size should be able to meet its grain demand using intercrop MSf1R and MSh1R of PS1. Such system could limit the trend to cultivate the marginal lands thereby conserving the grazing lands. Although no DM yield advantage was found in PS1, the moderate increase of CP concentration may alleviate the nutritional constraints of the livestock.

In the second planting strategy (PS2), there appeared to be distinct tradeoffs in grain and feed output when millet and stylo were intercropped. Millet grain yield decreased 26% to 51% in MSf1R, 57% to 73% in MSh1R, and up to 83% in the alternate triple-row planting patterns over 2 yr. Intercrop total DM increased by 15% to 45%, and CP concentration was raised 84% to 127% from that of PM crop. Millet dominated the intercrops in PS1. However, when stylo regrew from stubble (PS2) stylo became the dominant species

in the intercrop. Higher legume yield in PS2 relative to PS1 reduced millet yield but increased overall DM and crude protein yields. Although a large grain yield reduction was observed in PS2, major benefits may derive from the increased DM yield and feeding value. Kouamé et al. (1991) reported that as little as 6 g N in the form of stylo supplemented to sheep fed millet residue yielded substantial liveweight gain. The additional 35 kg N ha⁻¹ obtained in MSf intercrop could, in theory, provide enough N to supplement 30 animals for 194 d. Such improved feeding system will be consistent with the common practice to fattening sheep 2 to 3 mo before the major religious holidays.

CHAPTER III
EFFECTS OF STYLOSANTHES INTERCROPPING ON WATER USE
EFFICIENCY AND SOIL CHEMICAL PROPERTIES

Introduction

With the growing concern over declining land productivity in Sub-Saharan Africa (SSA), more attention has been given to intercropping as a means of making more efficient use of available water and nutrient resources. Published data have clearly shown that intercropping can improve land productivity through efficient use of limited soil resources (Natarajan and Willey, 1980; Reddy and Willey, 1981; Marshall and Willey, 1983; Hook and Gascho, 1988). De and Singh (1979) reported that, under dry conditions, water use efficiency (WUE) of maize (Zea mays L.)/soybean (Glycine max L.) and maize/mungbean (Vigna radiata [L.] Wilczek) intercrops were 63% and 88% greater than that of monocrop maize. Under irrigated conditions, the authors found that water use (WU) of sugarcane (Saccharum officinarum L.) was 1% to 9% lower than that of sugarcane/cowpea (Vigna spp.) or sugarcane/castor (Ricinus communis L.) intercropping, respectively. Snaydon and Harris (1979) reviewed the mechanisms of intercropping that lead to more effective use of resources and concluded that below-ground interactions such as root zonation and nutrient

and water uptake often give rise to yield advantages in intercropping. It was also indicated that the largest advantages usually occur when legumes and non-legumes are intercropped. The use of different sources of nitrogen (N) and the release of legume-fixed N to the associated non-legume crop may contribute to the increase in N uptake and the efficient utilization of N by legume/grass intercrops (Hook and Gascho, 1988).

In the Sahel, the availability of soil N, phosphorus (P), and water limit plant growth and yield (Penning de Vries and Djiteye, 1982; Breman and de Wit, 1983; Bationo et al., 1990). There is a need for more effective utilization of soil resources under the unreliable rainfall conditions prevalent throughout the zone. Increased WUE of intercropping over sole cropping recently has been reported for millet (Pennisetum glaucum [L.] R.Br.)/cowpea (Vigna unguiculata [L.] Walp.) on a grain yield basis (Nourri and Reddy, 1991), and millet/stylo (Stylosanthes spp.) on a biomass production basis (Garba and Renard, 1991). Soil nutrient and water use efficiencies and yields of forage legume intercropping systems need to be assessed if such systems are to become alternative food and feed production strategies in the Sahel. The objectives of this study were to measure the efficiency of water use and changes in selected soil properties under different millet/stylo intercropping systems.

Materials and Methods

Water use efficiency and selected soil chemical characteristics were estimated together with millet grain and stover, and stylo yields, in a series of trials outlined in Chapter II. The experiments were conducted during 1989 and 1990 at the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) Sahelian Center (ISC) located at Sadoré (13°15'N latitude, 2°18'E longitude) in the Republic of Niger. The sandy soil (Siliceous, Isohyperthermic, Psammentic Paleustalf) of ISC is acidic (pH = 5.6 in 1:1 soil:water mixture) and low in native fertility (West et al., 1984).

Experimental treatments consisting of two planting strategies (PS1 and PS2) and seven cropping patterns were laid out as a split plot experiment in a randomized complete block design. Soil chemical properties were monitored at two experimental sites (site A=PS1 1988, PS2 1989; site B=PS1 1989, PS2 1990). Soil samples were taken at each site in the top 15-cm layer of each subplot with an 8-cm diameter auger at the beginning of the experiment (initial sampling period) and at the end of each cropping season (sampling period 1 and period 2 for 1989 and 1990 season, respectively). On each plot, five samples were taken and bulked, thoroughly mixed, subsampled, and analyzed for pH (1:1 soil:water), available phosphorus (Bray I), total N

(Kjeldahl), and organic matter (OM) (Walkley and Black as modified by Nelson and Sommers, 1982).

Soil water was measured only in PS2, where millet was sown into year-old, pre-established stylo, with a neutron probe (solo 25, Nardeux Humisol, France) every 15 d throughout the growing season. Measurements were taken at 10, 20, and 30 cm and at every 20 cm until a 170-cm depth. Total WU was calculated with a water balance equation (Jensen, 1973). Water use efficiency was computed using the formula:

$$\text{WUE} = (\text{DM or grain yield, kg ha}^{-1}) / (\text{Total water use, mm}).$$

Analysis of variance using the general linear model procedures (SAS Institute, 1982) was performed with difference in treatment means determined by least significant difference (LSD) methods or single-degree-of-freedom orthogonal contrasts whenever appropriate.

Results and Discussion

Water Use Efficiency

Total water use in PS2 was influenced by cropping pattern and year of study. Total WU was higher in 1989 than in 1990. Analysis of variance, however, showed no significant cropping pattern by year interaction, the WU differing mainly in magnitude from 1989 to 1990. Average effects were, therefore, presented and discussed (Table 3.1). Total WU of MSf intercrop was higher ($P=0.03$) than

Table 3.1. Water use (WU) and water use efficiency (WUE) of millet/stylo cropping patterns.

Cropping pattern [‡]	WU mm	WUE [†]		
		DM	grain	stover
		kg mm ⁻¹		
Pure millet	383.0	9.3	2.2	9.3
Intercrop MSf1R	384.1	10.2	1.1	5.8
Intercrop MSf3R	371.2	9.0	1.3	4.2
Intercrop MSh1R	367.0	14.5	0.7	3.5
Intercrop MSh3R	366.3	12.2	1.0	3.4
Pure <u>S. fruticosa</u>	369.7	8.7	-	-
Pure <u>S. hamata</u>	364.6	9.2	-	-
CV %	4	17	25	37
Contrast [§]				
Millet vs intercrop	0.07	0.01	0.01	0.01
Intercrop 1R vs 3R	0.16	0.01	0.05	0.27
Intercrop MSf vs MSh	0.03	0.01	0.01	0.06

[†] WUE = Output (dry matter, grain, stover)/Total water use.

[‡] Cropping pattern abbreviations: M=millet, Sf=Stylosanthes fruticosa, Sh=S. hamata, 1R=Alternate single-row planting arrangement, 3R=Alternate triple-row planting arrangement.

[§] Probability levels (F-test) for single-degree-of-freedom orthogonal contrast.

that of MSh, probably due to the deeper root system of Sf. Water use of PM was higher ($P=0.07$) than that of intercrop millet/stylo. Alternate triple-row planting tended ($P=0.16$) to consume less water than alternate single-row planting of millet/stylo intercrop.

Water use efficiency calculated on a total biomass basis (WUErd) indicated that millet/stylo intercrop produced more ($P<0.01$) biomass per unit of water uptake than pure crop of each intercrop component. The WUErd was higher ($P<0.01$) with alternate single-row planting than with alternate triple-row treatment. Intercropping systems that included Sh provided a more effective use of water than those involving Sf ($P<0.01$).

The improved WUErd of millet/stylo intercrops is likely due to the higher intercrops biomass yield than monocrops. Similar results were reported by Garba and Renard (1991) working with millet/Stylo intercrops. Our results, however, are only partially in agreement with Breman and de Wit (1983) who found that use of high amounts of water implied high DM production and high WUErd of fertilized Sahelian rangelands. The deep root system of Sf increase WU without a proportional increase of biomass production. This illustrated the conservative Sf response to water supply.

When calculated on the basis of only millet yield, the water use efficiency of grain production (WUEgr) for intercrop millet was 40% to 68% lower than that of PM

($P < 0.01$). Likewise, WUE of millet stover (WUE_{st}) was 37% to 63% higher in PM than in intercrop treatments ($P < 0.01$). Intercrops of MSh resulted in lower WUE_{gr} ($P < 0.01$) and lower WUE_{st} ($P = 0.06$) than MSf intercrops. Alternate triple-row intercrops produced more grain per unit of water consumed than alternate single-row treatments ($P = 0.05$). Low WUE of grain and stover production of intercropped millet reflected the poor performance of millet in PS2. Two-year-old stylo stands were so competitive that millet yield was greatly depressed. Greater millet yield decline of MSh intercrop led to lower WUE_{gr} and WUE_{st} than those of MSf intercrop. Using the combined grain yield of millet and cowpea, Nourri and Reddy (1991) found a higher WUE for grain production in intercrop millet/cowpea than monocrop of either crop. The fact that stylo does not contribute to edible grain yield of intercrops accounted, therefore, for the poor WUE_{gr} value.

Soil Chemical Properties

Soil analysis of samples taken at the beginning of the experiments showed differences in soil properties between the two sites. Site B contained 54% more OM, 51% more N, and 10% more available phosphorous (P) than site A which had the highest acidity. Effects of millet/stylo cropping system on those initial soil characteristics were, therefore, analyzed and discussed separately.

On site B, analysis of variance performed on all measured variables showed a significant ($P=0.02$) cropping pattern by sampling period interaction for P only (data not shown), implying that soil P concentration depended on cropping pattern at each sampling period. At the end of the first cropping season (1989), the pure stand stylo plots accumulated more ($P<0.01$) P than all other treatments, with Sf plots containing 62% more available P than initially measured (Table 3.2b). Intercrop millet/stylo tended ($P=0.11$) to yield less P than PM. By the end of the second season (1990), no significant effect in soil P concentration was found between intercrop and PM. However, MSf intercrops accumulated more ($P=0.08$) P than PM while Sh based intercrop tended ($P=0.13$) to do so. The pure stylo plots had higher ($P=0.02$) soil P concentration than those of PM. Soil P level at the second season was, however, similar to that recorded during the previous period.

Although the interaction of cropping pattern by period was not significant for P concentration at site A, main effects of sampling period and cropping pattern were highly significant ($P<0.01$). The surface soil in the pure Sf and Sh treatments had greater ($P=0.11$) P level at the end of the first cropping season (1988) than intercrop. The pure Sf plots contained 28% more P than PM plots, and about twice the initial P level. At the end of the second cropping season (1990), mean Sf-based plots contained more ($P=0.06$) P

Table 3.2. Soil phosphorous concentration as affected by cropping sequence and cropping pattern.

Site A

Cropping pattern [†]	Initial	Period [‡] 1	Period 2
	----- mg kg ⁻¹ -----		
Pure millet	4.4	6.7	6.1
Intercrop MSf1R	"	5.3	6.1
Intercrop MSh1R	"	4.9	6.0
Intercrop MSf3R	"	6.7	8.4
Intercrop MSh3R	"	8.1	6.6
<u>S. fruticosa</u>	"	8.7	9.1
<u>S. hamata</u>	"	7.2	5.8
CV %		33	19
Contrast [*]			
Millet vs intercrop		0.26	0.31
Millet vs Sf based		0.86	0.06
Millet vs Sh based		0.64	0.85
Stylo vs intercrop		0.02	0.14

Site B

Pure millet	4.8	5.5	4.8
Intercrop MSf1R	"	4.7	5.2
Intercrop MSh1R	"	4.4	5.3
<u>S. fruticosa</u>	"	7.8	6.9
<u>S. hamata</u>	"	6.3	6.4
CV %		16	18
Contrast [*]			
Millet vs intercrop		0.11	0.53
Millet vs Sf based		0.23	0.08
Millet vs Sh based		0.90	0.13
Stylo vs intercrop		0.01	0.02

[†] Cropping pattern abbreviations: M=millet, Sf=Stylosanthes fruticosa, Sh=S. hamata, 1R=Alternate single-row planting arrangement, 3R=Alternate triple-row planting arrangement.

[‡] Period 1, 2 = Sampling at the end of the first and second season, respectively; initial = initial sampling.

^{*} Probability levels (F-test) for single-degree-of-freedom orthogonal contrast.

than PM plots. All intercrop millet/stylo plots had generally higher P levels ($P < 0.01$) than the preceding sampling period. Annual application of 13 kg P ha⁻¹ may partly account for the increased available P from period to period. The high residual P levels from the stylo based cropping systems suggested a low P requirement which explained their adaptation to the low soil P condition of the Sahel. Other associative effects with soil fungi like mycorrhizae may be involved in stylo's ability to accumulate more P than millet. High residual P accumulation has been reported with other legume crops including peanut (Arachis hypogaea), Medicago spp., and ethiopian clovers (Trifolium spp.) (Fussell et al. 1987; Nnadi and Haque, 1988).

Unlike P, no period by cropping pattern interaction was found for pH, OM, and N at either site. Intercropping millet/stylo had little effect on soil OM concentration but affected soil pH and N concentrations (Table 3.3). When averaged over cropping treatments, site A soil pH-KCl, OM, and N concentrations tended to decrease from their initial value during the first cropping season and to increase to values equal to or higher than their initial values at the end of the second cropping season. A similar trend was observed at site B for pH-H₂O only. In contrast, soil N concentrations at that site increased during the first season and decreased to a level equal to the initial one at the second sampling period. Large fluctuations in climatic

Table 3.3. Mean soil pH, organic matter, and nitrogen level at the end of each cropping season.

Site A

Period	pH-kCl	pH-H ₂ O	Organic matter	Nitrogen
				----- g kg ⁻¹ -----
Initial	4.09 a [†]	4.87 c	3.08 ab	0.143 b
Season 1	4.02 b	5.07 b	2.80 b	0.129 b
Season 2	4.14 a	5.17 a	3.29 a	0.160 a

Site B

Initial	4.76 a	5.61 ab	4.76 a	0.215 b
Season 1	4.57 b	5.50 b	4.84 a	0.242 a
Season 2	4.37 c	5.74 a	4.56 a	0.214 b

[†] Means followed by the same letter in the same column are not different at 0.05 level of the Least Significant Difference test.

conditions likely influenced the surface soil which resulted in a variation of the chemical properties. Except for soil N, the range of variation was, however, small at each site for all other measured variables. This suggested that there may not have been any biological significance. The large variation in soil N may have been due to some mineralization that occurred during storage. Soil samples were stored for a prolonged period at room temperature before being analyzed. Mineralization may, therefore, have continued during the storage and may have affected the samples' N concentration.

Conclusion

Water is a major resource limiting crop production in the Sahel. Rainfall dictates the growing season (4 mo) and controls the effectiveness of most management practices. The improved productivity of the farming system will depend on the judicious utilization of the available soil moisture. Sole cropping of annual crops is often unable to use all the water stored in the soil (Sivakumar, 1990; Ong et al., 1991). This can be viewed as a waste of the much-needed moisture. On the other hand, intercropping annual crops or annual and perennial crops may increase the productivity by effectively using the available moisture (Ong et al., 1991; Garba and Renard, 1991).

Intercropping millet/stylo increased water use efficiency with respect to vegetative biomass (fodder) production. An additional 2.9 to 5.2 kg DM per unit of water consumed as compared to PM was obtained with MSh intercrop. In terms of grain production, however, water use efficiency was reduced in intercrop by some 40% to 67%, with greatest decline resulting from MSh intercrop. High combined millet and stylo DM yields in intercrop coupled with the lack of contribution of stylo to edible grain yield resulted in contrasting water use efficiency values. The results indicate that the association of millet and S. fruticosa increases the efficiency of fodder production without adversely affecting millet grain yield. Stylosanthes fruticosa could, therefore, be an excellent candidate for the development of water-use-efficient intercropping system. Both stylo species were found to accumulate more residual P in the soil than millet. That suggests a low P requirement and a possible association with mycorrhizae which enables Sf and Sh to adapt to soil with low P. These species could, therefore, save a considerable amount of applied P to the subsequent crops.

CHAPTER IV
EFFECTS OF STYLOSANTHES INTERCROPPING ON YIELDS AND
NITROGEN NUTRITION OF SUBSEQUENT MILLET CROP

Introduction

The beneficial effects of legumes on the production of subsequent non-legume crops have been well recognized. Rowland et al. (1988) reported from Australia that unfertilized wheat (Triticum durum L.) following lupin (Lupinus spp.) had 41% greater grain yield than continuous wheat. In the Philippines, rice (Oryza sativa L.) yields following incorporation of cowpea (Vigna unguiculata [L.] Walp.) crop residue and green manure were 14% and 19% higher, respectively, than those from fallow land (John et al., 1989). These authors also indicated that even when all above-ground cowpea biomass was removed, rice yield was similar to that following fallow. Mohamed-Saleem and Otsyina (1986) in Nigeria reported that maize (Zea mays L.) grain yield following 3-yr Stylosanthes hamata (L.) Taub. 'Verano' and 2-yr S. guianensis (Aub.) SW. 'Cook' crops harvested as hay, were three- and four-fold greater, respectively, than maize following maize without nitrogen (N) fertilization. These yield increases were equivalent to yields of continuous maize fertilized with 90 to 110 kg N ha⁻¹. Data from the USA showed that sorghum (Sorghum bicolor

[L.] Moench) did not respond to N fertilization when following legume hay crops such as crimson clover (Trifolium incarnatum L.), sub clover (T. subterraneum L.), hairy vetch (Vicia villosa Roth.) and common vetch (V. sativa L.) (Hargrove, 1986) or soybean (Glycine max L.), sweetclover (Melilotus officinalis L.), and red clover (T. pratense L.) (Peterson and Varvel, 1989). Grain yield per unit N uptake of wheat was 5% to 24% greater following alfalfa (Medicago sativa L.), sweetclover, red clover, and hairy vetch hay crops than after wheat (Badaruddin and Meyer, 1989). Likewise, an 83% to 86% increase in wheat grain yield was reported in Australia when the cereal followed lupin harvested as hay (Doyle et al., 1988). Yield reduction of non-legume crops following legumes have, however, been reported. These effects have been attributed to soil water deficit (Stickler et al., 1959; Pierce and Rice, 1988; Peterson and Varvel, 1989b).

Additional advantages of legume associations with non-legumes include the enhancement of soil physical properties, a reduction in pest and weed incidence, and a better nutrient cycling (Hoyt and Leitch, 1983; Hargrove, 1986; Bruulsema and Christie, 1987). Waghmare and Singh (1984b), working in India, reported that N fertilizer needs were reduced from 108 kg to 38 kg ha⁻¹ when wheat was grown after sorghum-cowpea or sorghum-peanut (Arachis hypogaea L.) intercrops. Soil nitrite levels in the spring following

alfalfa and various clovers (Trifolium spp.) harvested for hay was reported to be higher than those following wheat fertilized with 112 kg N ha⁻¹ as ammonium nitrate (Badaruddin and Meyer, 1989). Recently, legumes have been found to efficiently use insoluble soil phosphorus (P) and thereby increasing the pool of available P for the following crops (Gardner et al. 1981, 1983). Improved water infiltration on heavy soils was credited to legumes through deep penetration of their tap root into the soil profile (Carreker et al., 1968; Mannering and Johnson, 1969).

The N supplied by the legumes is usually considered their greatest asset. Legume-fixed N is critical for low-income farmers as it is the only renewable soil fertility input farmers can acquire without major investment. Nitrogen is fixed through the symbiotic relationship between the plant and a compatible Rhizobium bacteria. The rhizobia invade the legume root system forming a nodule where N gas from the atmosphere is reduced to N forms (ammonia) that are used by the legume in making protein. Legume-fixed N becomes available to the succeeding non-legume crop upon decomposition of roots and/or top materials in the soil. The quantity of legume-fixed N assimilated by a succeeding crop is quite variable and depends on such factors as the legume species and yield, initial soil N status, harvest management, etc. The net increase in soil available N may be fairly large if the native soil N level is low. Little

net increase in available N due to the legume may be realized if initial soil N levels are high (Hoyt and Leitch, 1983; Hargrove, 1986).

Legumes used as green manure or forage may provide large amounts of N to a succeeding crop (Mohamed-Saleem and Otsyina, 1986; Bruulsema and Christie, 1987; Badaruddin and Meyer, 1989; John et al., 1989). Legumes grown for grain, however, can deplete soil organic N (Juo and Lal, 1977; ICRISAT, 1985). Jones (1974) found that cowpea did not increase surface soil N concentration, and the yield of maize following cowpea was lower than maize following groundnut or cotton (Gossypium spp). Nnadi and Balasubramanian (1978) reported that varietal differences in cowpea root N concentration, root mass, and rate and extent of root N mineralization accounted for the variation in their capacity to increase soil N status when the tops are not returned to the soil. When grain legume yields are low, however, there can be substantial N contributions to subsequent cereal (Marcellos, 1984).

The beneficial effects of legumes to succeeding crops are influenced by cropping systems, legume density, and the interval of time between harvest or incorporation of legume and planting of following crop. Kumar Rao et al. (1983) reported that unfertilized maize following sorghum/pigeonpea (Cajanus cajan [L.] Millsp.) intercrops would require an estimated additional 40 kg N ha⁻¹ to attain the same yield as

maize following pure pigeonpea crop. Maximum yield increases of non-legumes have, however, been reported following maize/greengram (Phaseolus aureus Roxb.), maize/cowpea, maize/calopo (Calopogonium mucunoides Desv.), oat (Avena sativa L.)/clover, and sorghum/clover intercrops (Agbola and Fayemi, 1972; Nair et al., 1979; Varvel and Peterson, 1990). Each cropping system influences the growth and development of legume in a different way. Consequently, biomass production, the quantity of N fixed, and the proportion of plant material contributing to soil N vary with legume types and their management.

Soils in the Sahel of West Africa are very low in N and P. Since fertilizers are largely unavailable, legumes can play an important role in improving the productivity and sustainability of cereal production. Farmers are reluctant, however, to devote land and other resources to forage production. There is a need to demonstrate the effect of forage legumes on soil fertility and advantage to cereal production. The objective of this study was to evaluate the effects of Stylosanthes intercropping systems on the production and N nutrition of a subsequent millet crop.

Materials and Methods

The impacts of Stylosanthes integration into millet based cropping systems on the yields and N nutrition of subsequent millet crops were evaluated during 1989 and 1990

cropping seasons at the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) Sahelian Center (ISC), located at Sadoré (13°15'N latitude, 2°18'E longitude) in the Republic of Niger. The well drained sandy soil (Siliceous Isohyperthermic Psammentic Paleustalf) of ISC is acidic (pH = 5.6 in 1:1 soil:water), and low in native fertility (West et al., 1984). Long term yearly rainfall averages 560.0 mm; rainfall was 623.0 mm in 1989 and 399.5 mm in 1990. During the study period, mean monthly rainfall, minimum and maximum temperatures, and relative humidity were calculated from daily recordings.

Two separate experiments (trials A and B) were conducted by growing millet (Pennisetum glaucum [L.] R.Br.) cultivar CIVT, a recommended variety in the region, on 9 by 12 m plots previously cropped to seven millet and/or stylo cropping patterns described in Chapter II: 1) pure millet (PM), 2) pure S. fruticosa (Sf), 3) millet + S. fruticosa in alternate single-row (MSf1R), 4) millet + S. fruticosa in alternate triple-row (MSf3R), 5) pure S. hamata (Sh), 6) millet + S. hamata in alternate single-row (MSh1R), and 7) millet + S. hamata in alternate triple-row (MSh3R). Trial A was conducted in 1989 and 1990 on plots established in 1988 and 1989 respectively, as planting strategy I. Trial B was conducted in 1990 only, after millet and stylo have been grown successively for 2 yr (planting strategy II, Chapter II). Both trials A and B were laid out and managed

similarly. At the end of the preceding season, all above-ground biomass was removed from the field. Stylo was cut at 15-cm stubble height and the millet at ground level. Prior to sowing millet across the entire plot the following year, each plot received an equivalent application of 13 kg P ha^{-1} as single superphosphate which was broadcast and worked into 40 to 50 cm tall ridges with an oxen-drawn plough after the first rains. Stylo crowns and early season regrowth were incorporated into the ridges. Planting occurred on 30 June 1989 (Trial A) and 30 May 1990 (Trials A and B). Ten to twenty seeds were hand-sown in a pocket at 1.0-m spacing on ridges 0.75-m apart making $13,300 \text{ pockets ha}^{-1}$. Three weeks after sowing, millet was thinned to three plants per pocket. Each plot was divided into four subplots of 13.5 m^2 each. Four N rates (0, 15, 30, & 60 kg N ha^{-1}) were randomly assigned to the subplots. Nitrogen fertilizer was applied as urea in two equal applications, 3 and 6 wk post emergence. Experimental treatments for each trial consisted of the seven different previous cropping patterns and the four N rates arranged as split plots in a randomized complete block design. The treatments were replicated four times, with previous cropping patterns assigned to main plot and N rates assigned to subplots.

To determine treatment effects on yields, total millet biomass from the innermost 4 m^2 of each subplot was hand-harvested and weighted. Millet was fractionated into

panicles, leaf (blade + sheath), and stem. Samples of each plant part were sun-dried to constant weight for dry weight determination. Panicles were threshed to determine grain yield. Grain, leaf, and stem subsamples were milled to pass 1-mm screen, acid-digested using a modification of the aluminum block digestion procedure (Gallaher et al., 1975) with N and phosphorus (P) determined after distillation, respectively by titration and semi-automated colorimetry (Hambleton, 1977). Analysis of variance using the general linear model procedures (SAS Institute, 1982) was used to determine the treatment effects on millet grain, stover, N, and P yields. Single-degree-of-freedom orthogonal contrast was used to separate difference in treatment means. Linear and quadratic effects of N rate were tested using polynomial orthogonal contrast (Robson, 1959).

Results and Discussion

Trial A: One-year Residual Effect

Millet grain and stover yields and nutrient uptake varied according to previous cropping pattern, fertilizer N, and year of study (Table 4.1). The growing seasons were characterized by poorly distributed and/or insufficient rains. A particularly severe drought period occurred in June 1989, during the crop establishment period, and in August 1990, during the grain development phase. Together with other factors, the drought caused poor crop development

Table 4.1. Probability levels (F-test) for year, 1-yr previous cropping (PG), fertilizer nitrogen (FN), and interaction effects on millet yields and nutrient concentration.

Source	----- Response -----			
	Grain	Stover	N-uptake	P-uptake
Year	0.01	0.01	0.01	0.02
Previous Cropping (PG)	0.04	0.01	0.08	0.09
Year X PG	0.32	0.33	0.74	0.71
Fertilizer N (FN)	0.19	0.01	0.01	0.12
FN X PG	0.87	0.83	0.98	0.98
FN X Year	0.10	0.09	0.48	0.03
FN X PG X Year	0.83	0.29	0.11	0.32

Source	----- Response -----					
	N concentration			P concentration		
	Leaf	Stem	Grain	Leaf	Stem	Grain
Year	0.01	0.02	0.20	0.01	0.01	0.01
Previous Cropping (PG)	0.61	0.10	0.67	0.05	0.31	0.14
Year X PG	0.06	0.71	0.90	0.01	0.15	0.16
Fertilizer N (FN)	0.01	0.01	0.01	0.01	0.12	0.47
FN X PG	0.61	0.78	0.31	0.01	0.20	0.41
FN X Year	0.03	0.02	0.04	0.01	0.02	0.15
FN X PG X Year	0.84	0.98	0.12	0.01	0.03	0.14

and high yield variability. Given the important climatic effects on millet yields and nutrient use, data were analyzed and discussed on a yearly basis.

When millet and stylo are grown as monocrops or intercrops for one season and are followed the next season by PM, no differences in grain yield due to previous cropping were found in 1990 (Table 4.2). In 1989, previous cropping patterns affected ($P=0.06$) millet grain yield. Overall yield variability was high in 1989 with CV ranging from 52% to 76% (Table 4.3). During the 1990 season, alternate triple-row millet/stylo intercrops were not included in the experiment, leaving only five cropping patterns for testing. Analysis of variance of grain yield response to N fertilizer indicated little N effect ($P=0.11$) in 1989 and no N effect in 1990. There was no interaction of PG by FN in either year. Although unfertilized millet grain yield differed greatly in 1989, no difference was detected between previous millet and stylo based cropping effects, likely due to high variability. Across N rates, millet grain yield in 1989 was higher ($P=0.05$) following Sf-based treatments than PM and higher ($P<0.01$) following MSf than MSh intercrops (Table 4.3). During both 1989 and 1990, millet grain yield following stylo-based treatments tended to be higher than that of continuous millet. At the zero N level, grain yield of millet following pure Sh and Sf were, respectively, 85% and 92% greater in 1989 and 57% and 26%

Table 4.2. Probability levels (F-test) for 1-yr previous cropping (PG), fertilizer nitrogen (FN), and PG by FN interaction effects on millet yields and nutrient concentration in 1989 and 1990.

Source	Response [†]					
	Grain	Stover	N-upt	P-upt	NUE	N-part
1989						
Previous cropping (PG)	0.06	0.05	0.02	0.09	0.69	0.59
Fertilizer N (FN)	0.11	0.01	0.01	0.01	0.01	0.12
PG X FN	0.67	0.60	0.66	0.76	0.57	0.76
1990						
Previous cropping (PG)	0.40	0.20	0.16	0.40	0.17	0.66
Fertilizer N (FN)	0.39	0.63	0.01	0.68	0.01	0.01
PG X FN	0.89	0.55	0.61	0.74	0.88	0.68

Source	Response					
	N concentration			P concentration		
	Leaf	Stem	Grain	Leaf	Stem	Grain
1989						
Previous cropping (PG)	0.26	0.23	0.78	0.01	0.29	0.19
Fertilizer N (FN)	0.01	0.01	0.01	0.01	0.08	0.56
PG X FN	0.93	0.99	0.23	0.01	0.12	0.28
1990						
Previous cropping (PG)	0.26	0.43	0.75	0.58	0.31	0.23
Fertilizer N (FN)	0.01	0.01	0.01	0.01	0.24	0.01
PG X FN	0.03	0.46	0.73	0.29	0.56	0.97

[†] N-upt = N uptake, P-upt = P uptake, N-part = N partition
 NUE = Nitrogen use efficiency.

Table 4.3. Millet grain and stover yields following 1-yr previous cropping patterns.

1989				
Previous cropping pattern†	---- Grain ----		--- Stover ---	
	Zero‡	Mean	Zero	Mean
----- Mg ha ⁻¹ -----				
Pure millet	0.26	0.44	0.74	1.53
Intercrop MSf1R	0.47	0.62	1.10	1.96
Intercrop MSf3R	0.55	0.66	1.79	2.41
Intercrop MSh1R	0.28	0.45	0.99	1.52
Intercrop MSh3R	0.30	0.34	0.85	1.26
<u>S. fruticosa</u>	0.51	0.65	1.70	2.13
<u>S. hamata</u>	0.49	0.61	1.47	1.72
CV %	76	52	59	36
Contrast*				
Millet vs intercrop	0.39	0.50	0.27	0.13
Millet vs Sf based	0.21	0.04	0.07	0.01
Millet vs Sh based	0.53	0.89	0.40	0.88
Intercrop MSf vs MSh	0.28	0.01	0.16	0.01
Millet vs stylo	0.25	0.06	0.08	0.11
1990				
Pure millet	0.90	1.03	3.04	3.27
Intercrop MSf1R	1.01	0.95	2.69	3.23
Intercrop MSh1R	1.18	1.01	3.57	3.32
<u>S. fruticosa</u>	1.13	1.15	3.55	3.78
<u>S. hamata</u>	1.41	1.11	3.34	3.73
CV %	25	32	15	24
Contrast*				
Millet vs intercrop	0.82	0.38	0.76	0.97
Millet vs Sf based	0.92	0.80	0.79	0.41
Millet vs Sh based	0.20	0.91	0.24	0.38
Intercrop MSf vs MSh	0.43	0.60	0.03	0.75
Millet vs stylo	0.24	0.60	0.25	0.10

† Cropping pattern abbreviations: M=millet, Sf=Stylosanthes fruticosa, Sh=S. hamata, 1R=Alternate single-row planting arrangement, 3R=Alternate triple-row planting arrangement.

‡ Zero = No fertilizer N applied; Mean = Mean of 4 N rates.

* Probability levels (F-test) for single-degree-of-freedom orthogonal contrast.

greater in 1990 than grain yield of millet following PM. Optimum grain yield, with respect to efficiency of fertilizer use, was achieved when 15 kg N ha^{-1} was applied.

Increased millet grain yield following stylo and millet/stylo was likely due to rotational effects of the legumes. Beneficial effects of legumes, such as increased soil N pool, improvement of soil physical properties, increased availability of phosphorus and other nutrients may have contributed to millet yield increase. Soil analysis indicated that the 1990 experimental site contained higher nutrient levels than that of 1989 experimental site (Chapter III). This, in addition to the previous year stylo yield being low, may have rendered the effects of previous cropping patterns undetectable in 1990. Findings by Hoyt and Leitch (1983) showed that when native soil N level is elevated, little increase in available N due to the legume is realized.

That grain yield response to N was small could be attributed to lack of water which is known to reduce yield potential and render N unavailable to plants (Mughogho et al., 1985; Fussell et al., 1987). Christianson et al. (1990), using ^{15}N , showed that when the surface soil dries, N derived from urea remained in the top 15 cm soil layer where it is poorly absorbed by millet roots. The authors also found severe N losses associated with the urea point placement method. Following our urea-N application, a 10-

to 15-cm layer of dark brown circles appeared on the soil surface above the fertilizer placement site. This was accompanied by strong ammonia odor, indicating NH_3 movement to the soil surface and subsequent N loss.

Millet stover is an important by-product in Niger. It is used by farmers as animal feed (mostly leaves), building materials (stems), fuelwood (stover), and soil organic matter improver (part or whole plant). No significant interaction of PG by FN on stover yield was found during either study year (Table 4.2). In 1989, previous cropping patterns affected ($P=0.05$) millet stover yield. Cropping pattern effects approached significance ($P=0.20$) in 1990 possibly due to soil conditions at the testing site. Millet stover yield response to fertilizer N application was significant ($P<0.01$) only in 1989. At the zero N application level, millet stover yield in 1989 was greater ($P=0.07$) following the Sf-based treatments than PM with a trend ($P=0.16$) to be greater following MSf than MSH intercrop (Table 4.3). Across N application levels, millet stover yield in 1989 was higher ($P<0.01$) following Sf based cropping than PM, and higher ($P<0.01$) following MSf than MSH intercrop. That lead to a trend ($P=0.13$) toward higher millet stover yield following millet/styleo intercrop than following PM. The high stover yields produced in the sequence millet/styleo-millet were, perhaps, caused by the legume rotational effects. The consistent yield increase

following cropping systems that involved Sf suggest an enhanced residual effect by Sf.

Previous cropping system did not affect millet leaf, stem, and grain N concentrations in either 1989 or 1990 (Table 4.2). Application of N fertilizer, however, influenced ($P<0.01$) N concentration in all millet plant parts during both study years. The interaction of PG by FN was significant ($P=0.03$) for only leaf N in 1990. As N rates increased, millet leaf, stem, and N concentrations increased linearly ($P<0.01$) regardless of previous cropping. At the zero N level, stem N tended to be greater following Sf- and Sh-based treatment than PM in both years. In 1989, unfertilized millet grain N appeared to be higher ($P=0.11$) following Sf based cropping than PM and higher ($P=0.18$) following MSf than MSh (Table 4.4). Following pure stylo, N concentration of millet leaf, stem, and grain were consistently higher ($0.05<P<0.17$) than those of millet following millet in 1989.

Nitrogen uptake of millet was affected by previous cropping patterns ($P=0.02$ in 1989 and $P=0.16$ in 1990) and fertilizer N ($P<0.01$ in both years). The interaction of PG by FN was not significant during either study year (Table 4.2). During both 1989 and 1990, total N uptake of millet above-ground biomass increased linearly ($P<0.01$) with increasing N fertilizer rate, irrespective of previous cropping patterns. In 1989, total N uptake at the zero N

Table 4.4. Nitrogen concentration of millet leaf, stem, and grain following 1-yr previous cropping pattern.

1989						
Previous cropping pattern†	Leaf		Stem		Grain	
	Zero‡	Mean	Zero	Mean	Zero	Mean
----- g kg ⁻¹ -----						
Pure millet	11.5	13.5	5.3	7.9	19.7	22.7
Intercrop MSf1R	10.2	12.6	4.0	7.2	20.1	22.6
Intercrop MSf3R	12.5	14.6	7.0	8.9	23.1	24.5
Intercrop MSh1R	10.8	13.7	6.3	8.2	20.3	23.5
Intercrop MSh3R	10.0	14.1	6.2	9.2	20.7	24.2
<u>S. fruticosa</u>	13.7	15.7	8.0	10.0	22.9	24.5
<u>S. hamata</u>	11.6	14.6	6.5	9.7	21.7	23.8
CV %	15	18	19	30	8	14
Contrast*						
Millet vs intercrop	0.81	0.78	0.32	0.57	0.42	0.42
Millet vs Sf based	0.32	0.28	0.16	0.29	0.11	0.57
Millet vs Sh based	0.74	0.44	0.13	0.25	0.58	0.36
Intercrop MSf vs MSh	0.28	0.65	0.11	0.44	0.18	0.76
Millet vs stylo	0.17	0.04	0.02	0.04	0.11	0.53
1990						
Pure millet	7.1	10.8	2.6	6.7	17.1	21.1
Intercrop MSf1R	8.1	11.1	3.2	6.9	16.7	21.9
Intercrop MSh1R	7.7	11.5	3.3	7.2	17.4	21.8
<u>S. fruticosa</u>	7.2	10.7	4.8	7.7	16.7	21.5
<u>S. hamata</u>	7.0	10.0	4.5	7.7	17.6	21.8
CV %	12	11	31	39	11	9
Contrast*						
Millet vs intercrop	0.21	0.22	0.42	0.75	0.93	0.42
Millet vs Sf based	0.40	0.80	0.08	0.31	0.70	0.39
Millet vs Sh based	0.72	0.86	0.10	0.36	0.77	0.45
Intercrop MSf vs MSh	0.56	0.44	0.90	0.90	0.64	0.44
Millet vs stylo	0.94	0.24	0.01	0.11	0.99	0.42

† Cropping pattern abbreviations: M=millet, Sf=Stylosanthes fruticosa, Sh=S. hamata, 1R=Alternate single-row planting arrangement, 3R=Alternate triple-row planting arrangement.

‡ Zero = No fertilizer N applied; Mean = Mean of 4 N rates.

* Probability levels (F-test) for single-degree-of-freedom orthogonal contrast.

rate and at the mean of four N rates was higher ($P<0.01$) following Sf based cropping than PM and higher ($P<0.01$) following MSf than MSh (Table 4.5). Overall, N uptake in 1989 tended to be greater when millet followed intercrop millet/stylo than PM. In 1990, however, a trend to higher ($P=0.10$) N uptake in MSh treatments was observed at the zero N rate. Across N rates, N uptake was 56% and 19% greater in 1989 and 18% and 13% greater in 1990 following pure Sf and Sh, respectively, than following millet. Previous cropping effects on N uptake could be related to their effects on both N concentration and stover yield. Millet grain and stover yields following one-year millet and/or stylo cropping were, on average, two times greater in 1990 than those of 1989. In contrast, N concentration of millet leaf and stem were 1.3-times greater in 1989 than those of 1990. High millet biomass yield in 1990 resulted in a dilution of N, causing low N concentration in millet plant parts. On the other hand, millet plant parts in 1989 had a high N concentration due to low biomass yield. Greater millet biomass yield from plots previously cropped to pure or mixed stylo systems resulted in greater N uptake than the millet-millet sequence.

Previous cropping affected P concentration of only millet leaf ($P<0.01$) in 1989. Fertilizer N application affected P concentration of millet leaf ($P<0.01$) and stem ($P=0.08$) in 1989 and millet leaf ($P<0.01$) and grain ($P<0.01$)

Table 4.5. Nitrogen (N) and phosphorous (P) uptake of millet following 1-yr previous cropping pattern.

1989				
Previous cropping pattern†	N uptake		P uptake	
	Zero‡	Mean	Zero	Mean
----- kg ha ⁻¹ -----				
Pure millet	11.1	27.2	1.4	4.2
Intercrop MSf1R	16.6	33.3	2.8	4.5
Intercrop MSf3R	26.1	43.3	4.3	5.8
Intercrop MSh1R	14.5	27.3	2.2	3.8
Intercrop MSh3R	13.2	23.1	2.0	2.5
<u>S. fruticosa</u>	29.0	42.3	3.9	5.4
<u>S. hamata</u>	22.6	32.3	3.5	4.1
CV %	47	34	53	42
Contrast*				
Millet vs intercrop	0.19	0.21	0.35	0.52
Millet vs Sf based	0.01	0.01	0.10	0.39
Millet vs Sh based	0.86	0.91	0.97	0.17
Intercrop MSf vs MSh	0.01	0.01	0.05	0.08
Millet vs stylo	0.11	0.09	0.48	0.82
1990				
Pure millet	29.3	50.7	4.5	4.9
Intercrop MSf1R	31.2	49.7	4.5	5.1
Intercrop MSh1R	38.2	49.8	6.0	5.1
<u>S. fruticosa</u>	38.5	59.7	6.0	6.1
<u>S. hamata</u>	35.1	57.2	7.0	5.8
CV %	19	26	27	32
Contrast*				
Millet vs intercrop	0.49	0.87	0.51	0.84
Millet vs Sf based	0.43	0.39	0.49	0.29
Millet vs Sh based	0.10	0.54	0.08	0.44
Intercrop MSf vs MSh	0.19	0.97	0.25	0.96
Millet vs stylo	0.08	0.11	0.08	0.11

† Cropping pattern abbreviations: M=millet, Sf=Stylosanthes fruticosa, Sh=S. hamata, 1R=Alternate single-row planting arrangement, 3R=Alternate triple-row planting arrangement.

‡ Zero = No fertilizer N applied; Mean = Mean of 4 N rates.

* Probability levels (F-test) for single-degree-of-freedom orthogonal contrast.

in 1990. There was an interaction ($P < 0.01$) of PG by FN for only leaf P concentration in 1989. At the zero N rate, millet leaf, stem, and grain P concentrations in 1989 were higher in the millet-millet sequence than in the sequences intercrop MS-millet ($P < 0.01$), Sf-based millet ($0.01 < P < 0.07$), and Sh-based millet ($0.01 < P < 0.02$). No such trend was observed in 1990 (Table 4.6). Instead, unfertilized millet leaf P concentration was higher ($P = 0.08$) following intercrop MS than PM in 1990 and higher following Sf- ($P = 0.06$) and Sh- ($P < 0.01$) -based treatments than PM. When no N was applied, millet leaf P was higher following MSf than MSh in 1989 but not in 1990. Millet leaf P in 1989 ($P < 0.01$) and 1990 ($P < 0.01$) and grain P in 1990 ($P < 0.01$) increased linearly with increasing fertilizer N rates. High P concentrations in the millet-millet sequence was likely the result of less dilution in low millet biomass yield.

There were effects of previous cropping ($P = 0.09$) and fertilizer N ($P < 0.01$) on P uptake in 1989 only. The interaction of PG by FN did not affect total P uptake in either 1989 or 1990 (Table 4.2). Phosphorus uptake increased linearly ($P < 0.01$) with increasing N doses. In 1989, P uptake at the zero N level was greater ($P = 0.05$) when millet followed intercrop MSf than MSh and greater ($P = 0.10$) when millet followed Sf-based treatments than millet (Table 4.5). Across N rates, total P uptake was lower ($P = 0.08$) following MSh than MSf with a tendency to be lower ($P = 0.17$)

Table 4.6. Phosphorus concentration of millet leaf, stem, and grain following 1-yr previous cropping pattern.

1989						
Previous cropping pattern [†]	Leaf		Stem		Grain	
	Zero [‡]	Mean	Zero	Mean	Zero	Mean
----- g kg ⁻¹ -----						
Pure millet	1.87	1.81	1.69	1.54	3.98	4.01
Intercrop MSf1R	1.43	1.52	1.08	1.08	3.25	3.21
Intercrop MSf3R	1.73	1.58	0.88	1.02	3.87	4.13
Intercrop MSh1R	1.38	1.62	1.14	1.21	3.46	3.71
Intercrop MSh3R	1.25	1.33	1.01	1.03	3.35	3.35
<u>S. fruticosa</u>	1.58	1.66	1.07	1.33	3.61	3.66
<u>S. hamata</u>	1.57	1.45	1.13	1.07	3.37	3.58
CV %	17	9	31	59	4	43
Contrast [§]						
Millet vs intercrop	0.01	0.01	0.01	0.36	0.01	0.43
Millet vs Sf based	0.07	0.01	0.01	0.62	0.01	0.79
Millet vs Sh based	0.01	0.01	0.02	0.39	0.01	0.36
Intercrop MSf vs MSh	0.05	0.09	0.02	0.86	0.27	0.71
Millet vs stylo	0.08	0.01	0.02	0.25	0.01	0.58
1990						
Pure millet	0.44	0.89	0.42	0.47	3.04	2.60
Intercrop MSf1R	0.61	0.93	0.54	0.48	2.93	2.80
Intercrop MSh1R	0.58	0.96	0.73	0.50	3.05	2.60
<u>S. fruticosa</u>	0.61	0.95	0.61	0.53	3.41	2.91
<u>S. hamata</u>	0.90	1.08	0.70	0.63	3.14	2.60
CV %	22	20	48	44	14	22
Contrast [§]						
Millet vs intercrop	0.08	0.34	0.24	0.78	0.85	0.43
Millet vs Sf based	0.06	0.38	0.39	0.65	0.63	0.06
Millet vs Sh based	0.01	0.22	0.12	0.18	0.83	0.81
Intercrop MSf vs MSh	0.70	0.70	0.37	0.74	0.70	0.14
Millet vs stylo	0.01	0.04	0.20	0.14	0.39	0.42

[†] Cropping pattern abbreviations: M=millet, Sf=Stylosanthes fruticosa, Sh=S. hamata, 1R=Alternate single-row planting arrangement, 3R=Alternate triple-row planting arrangement.

[‡] Zero = No fertilizer N applied; Mean = Mean of 4 N rates.

[§] Probability levels (F-test) for single-degree-of-freedom orthogonal contrast.

following Sh-based treatments than PM. In 1990, however, P uptake of unfertilized millet was higher ($P=0.08$) following Sh-based treatments than PM. The high P uptake of Sf based cropping suggested by 1989 results was most likely due to higher millet yield from plots previously cropped to Sf systems. High correlations ($P<0.01$) were found between total P uptake and grain yield ($r=0.96$, and 0.85) and between total P uptake and stover yield ($r=0.96$ and 0.87) in 1989 and 1990, respectively.

Effective use of N in crop production is vital for resource-limited farmers in the tropics. Nitrogen use efficiency (NUE) defined as the ratio of grain yield to total N uptake, indicated little effect of previous cropping patterns and of PG by FN interaction in both 1989 and 1990. Nitrogen fertilization, however, decreased NUE ($P<0.01$) (Table 4.2). Maximum NUE values were achieved at the zero N application rate and decreased linearly ($P<0.01$) with increasing N doses. Across N rates, NUE was higher ($P<0.05$) when millet followed millet than following millet/styleo intercrops in 1990 (Table 4.7). The NUE of unfertilized millet following pure stands of both Sf and Sh tended to be low ($P=0.20$) in 1990. Hoyt and Leitch (1983) attributed such reaction to depletion of soil moisture by the legume hay crop. The decrease in NUE with increasing N rate is, however, likely due to increasing N accumulation in millet vegetative biomass rather than increasing grain production.

Table 4.7. Nitrogen (N) use efficiency (NUE) and N partitioning to grain of millet following 1-yr previous cropping pattern.

1989

Previous cropping pattern†	NUE		N partition	
	Zero‡	Mean	Zero	Mean
	--- kg kg ⁻¹ ---		---- % ----	
Pure millet	23.8	17.8	47.7	40.7
Intercrop MSf1R	28.3	19.9	57.2	44.4
Intercrop MSf3R	21.2	16.1	36.8	38.2
Intercrop MSh1R	20.2	17.1	40.7	39.0
Intercrop MSh3R	23.1	15.9	49.2	37.8
<u>S. fruticosa</u>	17.5	15.9	40.0	38.3
<u>S. hamata</u>	21.6	17.7	46.0	43.4
CV %	22	34	20	12
Contrast*				
Millet vs intercrop	0.54	0.88	0.64	0.55
Millet vs Sf based	0.37	0.77	0.62	0.96
Millet vs Sh based	0.75	0.93	0.80	0.62
Intercrop MSf vs MSh	0.66	0.99	0.30	0.93
Millet vs stylo	0.55	0.58	0.85	0.66

1990

Pure millet	30.6	23.5	52.3	48.4
Intercrop MSf1R	31.9	20.8	53.4	43.2
Intercrop MSh1R	30.7	21.2	53.4	44.0
<u>S. fruticosa</u>	28.8	20.9	48.3	43.1
<u>S. hamata</u>	28.6	19.8	52.2	42.5
CV %	15	18	11	17
Contrast*				
Millet vs intercrop	0.46	0.02	0.45	0.08
Millet vs Sf based	0.30	0.01	0.13	0.05
Millet vs Sh based	0.32	0.01	0.51	0.06
Intercrop MSf vs MSh	0.73	0.75	0.95	0.79
Millet vs stylo	0.20	0.01	0.15	0.04

† Cropping pattern abbreviations: M=millet, Sf=Stylosanthes fruticosa, Sh=S. hamata, 1R=Alternate single-row planting arrangement, 3R=Alternate triple-row planting arrangement.

‡ Zero = No fertilizer N applied; Mean = Mean of 4 N rates.

* Probability levels (F-test) for single-degree-of-freedom orthogonal contrast.

John et al. (1989) similarly reported a decrease in NUE with rice following various cowpea treatments and fertilized with varying levels of urea-N.

The amount of N partitioned to grain from the total N uptake is a major factor affecting grain protein concentration. Analysis of variance based on all N treatments indicated no effect of previous cropping and no PG by FN interaction on N partition to grain in either year (Table 4.2). Nitrogen fertilization, on the other hand, influenced N partitioning ($P=0.12$ and 0.01 in 1989 and 1990, respectively). Maximum proportion of N uptake went to the grain at low N levels (Table 4.7). As N applied increased to 30 & 60 kg N ha⁻¹, the amount of N partitioned to grain declined linearly ($P=0.07$ and 0.01 in 1989 and 1990, respectively). It appeared that increased availability of soil N increased millet grain N uptake up to a limit (of about 50% of total N uptake), after which further N uptake is mainly retained in millet stover.

Trial B: Two-year residual effects

When millet and stylo are grown as monocrops or intercrops continuously for 2 yr and are replaced by PM crop in the third year, previous cropping patterns ($P=0.04$) and N fertilizer ($P<0.01$) affected millet grain yield. There was no PG by FN interaction was not significant (Table 4.8). When averaged over N rates, millet grain yield was higher

Table 4.8. Probability levels (F-test) for 2-yr previous cropping (PG), fertilizer nitrogen (FN), and PG by FN interaction effects on millet yields and nutrient concentration in 1990.

Source	Response [†]					
	Grain	Stover	N-upt	P-upt	NUE	N-part
Previous cropping (PG)	0.04	0.19	0.11	0.02	0.06	0.01
Fertilizer N (FN)	0.01	0.01	0.01	0.02	0.01	0.06
PG X FN	0.69	0.40	0.50	0.78	0.96	0.84

Source	Response					
	N concentration			P concentration		
	Leaf	Stem	Grain	Leaf	Stem	Grain
Previous cropping (PG)	0.01	0.01	0.17	0.06	0.92	0.17
Fertilizer N (FN)	0.01	0.01	0.01	0.02	0.68	0.01
PG X FN	0.97	0.75	0.84	0.34	0.96	0.65

[†] N-upt = N uptake, P-upt = P uptake, N-part = N partition
NUE = Nitrogen use efficiency.

($P=0.06$) following millet/stylo intercrops than continuous PM (Table 4.9). Previous Sf-based treatments resulted in higher ($P=0.03$) grain yield of succeeding millet than those of PM (average of four N levels). At both zero and mean N rates, a trend to higher ($P=0.19$ and $P=0.12$, respectively) grain yield was observed when millet followed MSf than MSh intercrop. Grain yield response to increasing fertilizer rate was linear ($P<0.01$) over all previous cropping patterns. The increased grain yield of millet following stylo-based treatments may have been due to the legumes' positive role on soil physical and chemical properties. High yield variability in grain yield response to N could be ascribed to a drought spell that occurred during grain development period.

Unlike grain yield, intercropping millet and stylo for two successive years had little effect on succeeding millet stover ($P=0.19$) yield (Table 4.8). However, the low probability value suggests that some trends may exist due to previous cropping patterns. Fertilizer N influenced ($P<0.01$) millet stover yield. Stover dry weight increased linearly ($P<0.01$) with increasing fertilizer N doses. When no fertilizer N was applied, millet following millet/stylo intercrops had higher ($P=0.06$) stover yield than continuous PM, with rotation Sh-Sh-M producing 1.1 Mg ha^{-1} more biomass than continuous M-M-M system (Table 4.9). Previous cropping

Table 4.9. Millet grain and stover yields following 2-yr previous cropping pattern.

Previous cropping pattern [†]	Grain		Stover	
	Zero [‡]	Mean	Zero	Mean
	----- kg ha ⁻¹ -----			
Pure millet	0.80	1.02	2.04	2.85
Intercrop MSf1R	1.02	1.23	2.73	3.08
Intercrop MSf3R	1.14	1.33	2.92	3.24
Intercrop MSh1R	0.98	1.13	2.35	2.75
Intercrop MSh3R	0.81	1.15	2.83	3.21
<u>S. fruticosa</u>	0.85	1.22	2.11	3.08
<u>S. hamata</u>	0.86	0.92	3.13	2.99
CV %	29	31	22	20
Contrast [§]				
Millet vs intercrop	0.29	0.06	0.06	0.33
Millet vs Sf based	0.28	0.03	0.14	0.21
Millet vs Sh based	0.69	0.71	0.06	0.58
Intercrop MSf vs MSh	0.19	0.12	0.39	0.30
Millet vs stylo	0.86	0.14	0.18	0.44

[†] Cropping pattern abbreviations: M=millet, Sf=Stylosanthes fruticosa, Sh=S. hamata, 1R=Alternate single-row planting arrangement, 3R=Alternate triple-row planting arrangement.

[‡] Zero = No fertilizer N applied; Mean = Mean of 4 N rates.

[§] Probability levels (F-test) for single-degree-of-freedom orthogonal contrast.

patterns that included Sf consistently tended to produce more stover than PM.

Effect of period of drought spell on millet production is well-known in the Sahel (Christianson et al., 1990; Sivakumar, 1991). The occurrence of drought near the end of the 1990 cropping season did not affect stover yield, unlike grain yield. The early onset of rain in 1990 and relatively good distribution promoted rapid stover growth which was terminated at time of drought occurrence. High millet stover yield following previous stylo-based treatments was likely due to the better growing conditions provided by the previous legume crops. The lack of difference in stover yield of the different treatments when N fertilizer was applied suggested that the residual N from the previous legumes was not that great, and/or urea-N loss may have been important due to drought condition that developed in August.

Previous cropping pattern affected millet leaf ($P < 0.01$) and stem ($P = 0.03$) N concentrations (Table 4.8) but not grain N concentration. There was a positive effect of N fertilization on millet leaf, stem, and grain N concentrations were significant ($P < 0.01$) but no interaction of PG by FN was found. Millet stem N concentration was lower ($P = 0.07$) following Sf-based treatments than millet (average of four N rates). Similar trends were observed for unfertilized millet leaf ($P = 0.18$) and stem ($P = 0.20$) N concentrations following Sf-based treatments (Table 4.10a).

Table 4.10. Nitrogen and phosphorous concentrations of millet leaf, stem, and grain following 2-yr previous cropping pattern.

A. Nitrogen

Previous cropping pattern†	Leaf		Stem		Grain	
	Zero‡	Mean	Zero	Mean	Zero	Mean
	----- g kg ⁻¹ -----					
Pure millet	8.5	11.0	3.9	5.5	14.5	19.4
Intercrop MSf1R	6.9	10.4	2.9	4.6	13.4	18.7
Intercrop MSf3R	9.5	11.9	3.4	4.9	14.3	19.3
Intercrop MSh1R	7.5	10.3	3.3	4.7	15.8	20.5
Intercrop MSh3R	8.2	12.0	3.8	5.7	14.7	19.0
<u>S. fruticosa</u>	7.1	10.4	3.0	5.0	14.2	19.6
<u>S. hamata</u>	9.9	12.5	3.2	6.0	16.9	20.6
CV %	19	16	22	22	18	11
Contrast*						
Millet vs intercrop	0.24	0.95	0.29	0.13	0.89	0.99
Millet vs Sf based	0.18	0.53	0.20	0.07	0.73	0.78
Millet vs Sh based	0.39	0.37	0.39	0.86	0.44	0.34
Intercrop MSf vs MSh	0.66	0.85	0.32	0.16	0.30	0.19
Millet vs stylo	0.35	0.62	0.27	0.90	0.56	0.33

B. Phosphorous

Pure millet	0.93	1.52	0.51	0.47	2.97	2.70
Intercrop MSf1R	0.90	0.96	0.60	0.41	3.18	2.74
Intercrop MSf3R	1.01	1.19	0.38	0.42	3.04	2.85
Intercrop MSh1R	0.75	0.81	0.49	0.37	3.35	2.64
Intercrop MSh3R	1.07	1.07	0.45	0.48	2.35	2.55
<u>S. fruticosa</u>	0.96	0.99	0.37	0.38	2.95	2.99
<u>S. hamata</u>	0.79	1.11	0.43	0.46	3.03	2.60
CV %	31	25	41	55	14	19
Contrast*						
Millet vs intercrop	0.38	0.42	0.84	0.50	0.90	0.97
Millet vs Sf based	0.58	0.71	0.77	0.27	0.79	0.26
Millet vs Sh based	0.20	0.36	0.62	0.75	0.58	0.52
Intercrop MSf vs MSh	0.60	0.10	0.98	0.49	0.15	0.14
Millet vs stylo	0.33	0.73	0.46	0.43	0.83	0.51

† Cropping pattern abbreviations: M=millet, Sf=Stylosanthes fruticosa, Sh=S. hamata, 1R=Alternate single-row planting arrangement, 3R=Alternate triple-row planting arrangement.

‡ Zero = No fertilizer N applied; Mean = Mean of 4 N rates.

* Probability levels (F-test) for single-degree-of-freedom orthogonal contrast.

Nitrogen concentration in all millet plant parts showed a positive linear ($P < 0.01$) response to FN.

Total N uptake was unaffected by previous cropping patterns. There was an effect of N fertilization on total N uptake but no PG by FN interaction was found (Table 4.8). At the zero N level, total N uptake of millet following pure Sf was low (Table 4.11). High millet N concentration from PM and Sh based plots were in inverse relation with their low biomass yield. Nitrogen concentration was generally low when millet grain and stover yields are high. This dilution effect resulted in similar total N uptake among the different cropping sequences.

Stylosanthes fruticosa and S. hamata differed in many aspects, including their life cycle and their herbage yield. Whereas the latter behaves as bi-annual in the Sahel (ICRISAT, 1987), with a dense root mass in the top 50-cm soil layer and a high herbage yield, the former (S. fruticosa) is a true perennial with a rather deep and strong tap root system which enhances its persistence. That caused the majority of S. hamata shoots to die after the second cropping season while the root and crown of S. fruticosa are incorporated fresh into ridges during field preparation. Although root N concentration of both species was similar (Kouamé, unpublished), the rate of decomposition and subsequent release of N to the following millet crops is likely different between the two species. That millet

Table 4.11. Nitrogen (N) and phosphorous (P) uptake of millet following 2-yr previous cropping pattern.

Previous cropping pattern†	N uptake		P uptake	
	Zero‡	Mean	Zero	Mean
	----- kg ha ⁻¹ -----			
Pure millet	23.9	44.5	3.81	5.52
Intercrop MSf1R	26.5	45.3	5.12	5.34
Intercrop MSf3R	34.2	52.2	5.40	6.30
Intercrop MSh1R	27.4	44.1	4.74	4.53
Intercrop MSh3R	28.0	50.0	3.92	5.53
<u>S. fruticosa</u>	22.5	48.7	3.94	5.84
<u>S. hamata</u>	31.6	45.7	4.18	4.66
CV %	27	19	22	28
Contrast*				
Millet vs intercrop	0.33	0.47	0.23	0.23
Millet vs Sf based	0.51	0.33	0.22	0.06
Millet vs Sh based	0.39	0.75	0.77	0.99
Intercrop MSf vs MSh	0.43	0.50	0.07	0.05
Millet vs stylo	0.70	0.61	0.98	0.56

† Cropping pattern abbreviations: M=millet, Sf=Stylosanthes fruticosa, Sh=S. hamata, 1R=Alternate single-row planting arrangement, 3R=Alternate triple-row planting arrangement.

‡ Zero = No fertilizer N applied; Mean = Mean of 4 N rates.

* Probability levels (F-test) for single-degree-of-freedom orthogonal contrast.

following Sf-based treatments consistently produced higher yields than Sh-based treatments could be due to longer supply of N through decomposition and efficient release of N during millet growth. Further, by producing twice as much DM as Sf, Sh likely exported more nutrients from the soil. This high nutrient uptake may have resulted in low yield of subsequent millet crops.

Previous cropping pattern affected leaf P concentration ($P=0.06$). Fertilizer N affected leaf P ($P<0.01$) and grain P ($P<0.01$). There was no interaction of PG by FN for P concentration of all millet fractions (Table 4.8). Across N rates, millet leaf ($P=0.10$) and grain ($P=0.14$) P following intercrop MSf tended to be greater than that of millet following MSh intercrop (Table 4.10b). Response of millet P to N fertilizer was variable. Whereas leaf P concentration linearly ($P=0.02$) increased following increasing N doses, grain P response was quadratic ($P<0.01$). Total P uptake was influenced by both previous cropping ($P=0.02$) and fertilizer N ($P<0.05$). There was no PG by FN interaction (Table 4.8). Phosphorus uptake of unfertilized millet was higher ($P=0.07$) following MSf than MSh (Table 4.11). When averaged over N rates, millet total P uptake was greater ($P=0.06$) following Sf-based treatments than PM and greater ($P=0.05$) following MSf than MSh intercrops. Total P uptake increased linearly ($P<0.01$) with increasing fertilizer N doses. Like in trial A, high millet P uptake observed on plots previously cropped

Table 4.12. Nitrogen (N) use efficiency (NUE) and N partitioning to grain of millet following 2-yr previous cropping pattern.

Previous cropping pattern [†]	NUE		N partition	
	Zero [‡]	Mean	Zero	Mean
	--- kg	kg ⁻¹ ---	---- %	----
Pure millet	33.7	25.2	48.9	47.1
Intercrop MSf1R	38.4	28.7	50.7	50.8
Intercrop MSf3R	33.3	26.6	47.6	50.0
Intercrop MSh1R	35.9	26.9	56.9	53.6
Intercrop MSh3R	29.1	24.0	42.5	43.7
<u>S. fruticosa</u>	38.0	27.6	54.2	51.2
<u>S. hamata</u>	27.3	21.2	40.8	40.7
CV %	25	26	18	20
Contrast [§]				
Millet vs intercrop	0.83	0.16	0.90	0.13
Millet vs Sf based	0.34	0.05	0.72	0.06
Millet vs Sh based	0.60	0.59	0.92	0.57
Intercrop MSf vs MSh	0.58	0.14	0.92	0.57
Millet vs stylo	0.65	0.63	0.90	0.74

[†] Cropping pattern abbreviations: M=millet, Sf=Stylosanthes fruticosa, Sh=S. hamata, 1R=Alternate single-row planting arrangement, 3R=Alternate triple-row planting arrangement.

[‡] Zero = No fertilizer N applied; Mean = Mean of 4 N rates.

[§] Probability levels (F-test) for single-degree-of-freedom orthogonal contrast.

to Sf systems was likely due to greater millet biomass yield.

Nitrogen use efficiency of millet following 2-yr millet and/or stylo cropping systems varied with previous cropping ($P=0.06$). The greatest NUE was obtained when millet followed cropping systems that included Sf. Fertilizer N affected ($P<0.01$) NUE with no PG by N interaction. The NUE was highest with unfertilized millet and decreased linearly ($P<0.01$) with increasing N application. Unfertilized millet NUE following Sf-based treatments was, on average, 15% higher ($P=0.34$) than that following PM. Across N rates, NUE was higher ($P=0.05$) following Sf based cropping than PM and tended to be higher ($P=0.14$) following MSf than MSh intercrop (Table 4.12). Following intercrop MS, NUE was generally higher ($P=0.16$) than following PM. Alternate single-row intercrop MSf lead to the production of 3.5 kg more grain per kg N uptake than the continuous PM system and 7.5 kg kg^{-1} more than the Sh-Sh-M sequence. Greater NUE associated with Sf-based treatments and lower NUE associated with Sh based treatments can be traced back to differences in the beneficial effect of the two species. It clearly appeared that Sf provided better conditions (residual N plus residual P) than Sh. Increasing N rates increased N uptake but this does not necessarily imply increased grain yield. Correlation analysis indicated that N uptake was positively

related to stover yield ($r = 0.80$, $p < 0.01$) and to grain yield ($r = 0.75$, $p < 0.01$).

Nitrogen partitioning was affected ($P = 0.01$) by 2-yr residual effects of millet and/or stylo cropping systems. Fertilizer N also affected ($P = 0.06$) N partitioning with no PG by FN interaction. The amount of N partitioned to grain (average of four N rates) was generally greater ($P = 0.13$) when millet followed intercrop millet/stylo than continuous millet (Table 4.12). Across N rates, millet following Sf-based treatments partitioned more ($P = 0.06$) N to grain than that following continuous millet. The application of increasing doses of N had a negative effect ($P = 0.02$) on N partitioning. Increased total N uptake resulting from increasing fertilizer N rate did not necessarily increase grain N uptake.

Conclusion

The beneficial effects of legumes on the production of subsequent crops depend on many factors including legumes species, environmental conditions, managements practices, etc. Although many authors have demonstrated the residual effects of sole legume crops (Rowland et al., 1988, Badaruddin and Meyer, 1989, John et al., 1989), little information is available on the residual effects of cereal/legumes intercropping.

Intercropping millet and stylo in our experiment offered up to a two-fold increase of subsequent millet grain and N yields over PM. The beneficial effect varied with stylo species, yearly rainfall distribution and the duration of previous cropping. The highest N concentrations and lowest uptakes during this study were produced in 1989. Yields in that year were low due to unfavorable growing conditions and N concentrations remained high due to less dilution in lower biomass production.

Although the soils in the Sahel are inherently low in native fertility, chemical fertilizer is rarely an option. Without N application, our study showed that growing millet after 1-yr millet/stylo intercrop produced 26% to 92% more grain than continuous millet culture. When millet and stylo were continuously intercropped for 2 yr, planting millet the third year also increased grain yield by 22% to 42% with zero N input. This is consistent with findings by Waghmare and Singh (1984) indicating that the rotational effects of Sorghum/cowpea and Sorghum/peanut reduced the need for fertilizer N of the subsequent wheat crop.

The results also showed that cropping systems that included Sf provided an efficient use of soil N, up to 3.5 kg additional grain yield per kg of N uptake in the 2-yr rotation. After 2-yr growth, Sf consistently increased yields of the succeeding millet crop. With N application, optimum millet grain yield with respect to fertilizer use

efficiency was produced at 15 kg N ha⁻¹ rate. Response to N fertilizer was greatest when Sf was included in the previous cropping.

The study suggests that growing millet after an intercrop millet/stylo may reduce the need for N fertilization. The native S. fruticosa consistently increased grain yield and maximized N utilization of the subsequent millet crop. These findings offer an incentive to develop practical, short-term millet/S. fruticosa intercropping and rotation systems.

CHAPTER V CONCLUSIONS

The dual production objectives of the farming systems in the Sahel are to produce enough food to assure the family's need and feed the crop residue to the livestock during the long dry season. The residues are either grazed in situ or harvested and stored for dry season feeding. The expansion of farms to marginal lands traditionally used for grazing has drastically lowered crop and animal production. A possibility to increase the production system may be to intercrop millet with perennial S. fruticosa and follow up with a pure millet crop in a short-term rotation system. Such a system may limit the pressure on the grazing lands, sustain soil productivity, and satisfy the food and feed demand. Our study showed that:

(1) Intercropping millet and stylo in alternate single rows resulted in a reduction of 0.18 Mg to 0.28 Mg ha⁻¹ of millet grain yield during the stylo seeding year. Yield reductions were greater when planted in the alternate-triple row pattern. Growing millet after MSf1R or MSh1R offered a grain yield increase of only 0.15 Mg to 0.16 Mg ha⁻¹ with no fertilizer N application, compensating merely for the yield loss incurred the previous year due to intercropping.

(2) Intercropping millet and stylo continuously for 2 yr further reduced millet grain yield the second year, due to increased competition for moisture. Yield declines were 0.48 Mg to 0.51 Mg ha⁻¹ in MSf1R, 0.58 Mg to 0.73 Mg ha⁻¹ in MSh1R, and as much as 0.83 Mg ha⁻¹ in alternate triple-row planting treatments. Growing millet the third year in rotation provided a maximum increase of only 0.34 Mg ha⁻¹ which did not compensate for the cumulative drop of grain yield incurred over the preceding 2 yr due to intercropping.

(3) Intercropping millet and stylo increased the crude protein concentration of the harvested fodder during the seeding year (planting strategy I), from 43 g to 48 g kg⁻¹ in PM up to 50 g to 75 g kg⁻¹ in alternate single-row intercrop, but did not increase the total DM harvested. In the second planting strategy, however, both crude protein concentration and feed output increased, respectively, by 12% to 17% and 56% to 151% for MSf1R and up to 106% and 127% in alternate triple-row planting systems relative to pure millet. Other advantages of 2-yr continuous intercropping included the efficient use of water for biomass production (2.9 to 5.2 extra kg DM per unit of water consumed), the efficient use of soil N (up to 3.5 kg additional grain per kg N uptake), and the accumulation of P in the soil by intercrop stylo.

By minimizing grain yield reduction of intercropped millet and improving grain yield and N use efficiency of the subsequent millet crop, native *S. fruticosa* has potential to

contribute to the development of sustainable food and feed production in the crop-livestock farming systems of the Sahel. The results also suggest that with a 50:50 (millet:stylo) planting ratio, the cropping sequence intercrop millet/stylo (MS)-millet benefitted food (grain) production whereas the sequence MS-MS-M favored feed and nutrient output. Because of the overriding importance of grain production, the latter scheme is unlikely to be accepted by farmers. Testing other planting ratios where millet would outnumber stylo (2:1 or 3:1) may yield a satisfactory balance between grain and fodder production. The high variability in soil and rainfall (onset, amount, and distribution) conditions and their inevitable impact on crop growth and nutrient use suggest that the study should be carried out over several years before developing final recommendations. With additional investigations and appropriate testings, short-term intercropping and rotation systems of millet and S. fruticosa may prove to be of great value to the low-input, crop-livestock farming system of the Sahel.

APPENDIX

Table A.1. Climatological data at the experimental station Sadoré, Niger in 1989 and 1990.

Month	Air Temperature				Relative Humidity		Temperature	
	Minimum		Maximum		at 1400		Soil at 5 cm	
	1989	1990	1989	1990	1989	1990	1989	1990
	----- °C -----				--- % ---		--- °C ---	
January	13.8	17.9	30.2	33.8	11.0	15.0	30.5	33.5
February	16.4	17.4	32.6	33.7	9.0	10.0	33.6	34.5
March	22.0	20.6	38.4	37.7	9.0	8.8	40.5	34.5
April	24.5	26.8	41.9	41.9	16.0	21.0	45.1	45.2
May	26.9	27.2	41.3	40.2	25.0	35.0	45.7	45.2
June	26.0	27.2	38.6	38.4	37.0	39.0	40.9	41.1
July	23.8	23.7	34.7	33.2	51.0	58.0	38.9	35.8
August	22.8	23.7	32.0	34.4	63.0	56.0	35.8	38.0
September	22.7	24.0	34.1	35.1	53.0	52.0	39.4	37.9
October	21.4	22.2	35.9	38.9	32.0	26.0	39.1	37.9
November	18.6	19.7	36.2	38.2	15.0	15.0	37.6	37.8
December	16.6	19.2	32.7	35.3	17.0	14.0	33.0	34.7

Table A.2. Probability levels (F-test) for planting strategy (PS), cropping pattern (CR), and PS by CR interaction effects on millet and stylo yields in 1989 and 1990.

1989				
Source	Millet Grain	Stover	Stylo Herbage	Total dry matter
Planting strategy (PS)	0.05	0.02	0.01	0.01
Cropping pattern (CR)	0.01	0.01	0.01	0.01
PS X CR	0.05	0.06	0.01	0.01
CV %	34	37	25	23
1990				
Planting strategy (PS)	0.48	0.02	0.01	0.01
Cropping pattern (CR)	0.01	0.01	0.01	0.01
PS X CR	0.01	0.07	0.01	0.01
CV %	25	26	17	15

Table A.3. Nitrogen (N) concentration of stylo leaf and stem at the first harvest of planting strategy II.

A. Leaf N

Cropping pattern†	----- 1989 -----		----- 1990 -----	
	fruticosa	hamata	fruticosa	hamata
	----- g kg ⁻¹ -----			
Pure stylo	28.8	--‡	28.1	28.4
Intercrop 1R	29.0	33.0	28.0	28.6
Intercrop 3R	28.2	30.2	26.2	26.0
CV %	10	5	4	5
Contrast‡				
Stylo vs intercrop	0.87	--	0.27	0.14
Intercrop 1R vs 3R	0.79	0.91	0.05	0.05

B. Stem N

Pure stylo	15.4	--	12.5	14.0
Intercrop 1R	13.6	12.4	14.1	12.6
Intercrop 3R	16.2	12.4	12.7	13.1
CV %	5	9	10	11
Contrast‡				
Stylo vs intercrop	0.31	--	0.11	0.35
Intercrop 1R vs 3R	0.01	0.96	0.82	0.43

† Cropping pattern abbreviations: M=millet, Sf=Stylosanthes fruticosa, Sh=S. hamata, 1R=Alternate single-row planting arrangement, 3R=Alternate triple-row planting arrangement.

‡ Pure stylo Sh was not harvested at first cutting

§ Probability levels (F-test) for single-degree-of-freedom orthogonal contrast.

Table A.4. Phosphorous (P) concentration of stylo leaf and stem at the first harvest of planting strategy II.

A. Leaf P

Cropping pattern†	1989		1990	
	fruticosa	hamata	fruticosa	hamata
	g kg ⁻¹			
Pure stylo	2.87	--‡	2.67	2.15
Intercrop 1R	2.36	2.08	2.12	2.16
Intercrop 3R	2.87	2.11	2.52	2.38
CV %	15	3	9	14
Contrast*				
Stylo vs intercrop	0.20	--	0.02	0.61
Intercrop 1R vs 3R	0.62	0.55	0.09	0.35

B. Stem P

Pure stylo	2.18	--‡	1.80	1.57
Intercrop 1R	1.95	1.77	1.80	1.42
Intercrop 3R	1.99	1.54	1.92	1.76
CV %	4	2	13	15
Contrast*				
Stylo vs intercrop	0.02	--	0.70	0.14
Intercrop 1R vs 3R	0.59	0.01	0.51	0.32

† Cropping pattern abbreviations: M=millet, Sf=Stylosanthes fruticosa, Sh=S. hamata, 1R=Alternate single-row planting arrangement, 3R=Alternate triple-row planting arrangement.

‡ Pure stylo Sh was not harvested at first cutting

* Probability levels (F-test) for single-degree-of-freedom orthogonal contrast.

Table A.5. Stylo root-N concentration at first harvest, millet plant height at 60 d after planting, and panicle number at final harvest in planting strategy II.

Cropping pattern†	Stylo root N		Millet	
	1989	1990	Height	panicle
	----- g kg ⁻¹ -----		cm	No
Millet	--	--	147	68
Intercrop MSf1R	9.0	9.4	133	40
Intercrop MSf3R	10.1	11.0	102	34
Intercrop MSh1R	11.9	8.2	87	32
Intercrop MSh3R	10.4	10.9	101	35
<u>S. fruticosa</u>	11.3	11.6	--	--
<u>S. hamata</u>	--‡	11.4	--	--
CV %	16	17	16	17
Contrast‡				
Millet vs intercrop	--	--	0.01	0.01
Intercrop 1R vs 3R	0.31	0.13	0.41	0.68
Intercrop MSf vs MSh	0.10	0.86	0.02	0.38
Stylo vs intercrop	0.45	0.26	--	--

† Cropping pattern abbreviations: M=millet, Sf=Stylosanthes fruticosa, Sh=S. hamata, 1R=Alternate single-row planting arrangement, 3R=Alternate triple-row planting arrangement.

‡ Not included in the comparison

* Probability levels (F-test) for single-degree-of-freedom orthogonal contrast.

Table A.6. Relative dry matter yields of millet and stylo as affected by cropping pattern.

B. Planting strategy I

Cropping pattern†	----- 1989 -----			----- 1990 -----		
	Stover	Stylo	LER‡	Stover	Stylo	LER
Pure millet	1.00	0	1.00	1.00	0	1.00
Intercrop MSf1R	0.89	0.11	1.00	0.76	0.26	1.02
Intercrop MSf3R	0.89	1.53	2.42	0.69	0.50	1.19
Intercrop MSh1R	0.90	0.04	0.94	0.76	0.40	1.16
Intercrop MSh3R	0.47	0.60	1.07	0.48	0.48	0.96

B: Planting strategy II

Cropping pattern	----- 1989 -----			----- 1990 --		
	Stover	Stylo	LER	Stover	Stylo	LER
Pure millet	1.00	0	1.00	1.00	0	1.00
Intercrop MSf1R	0.46	0.66	1.12	0.70	0.52	1.22
Intercrop MSf3R	0.23	0.81	1.04	0.57	0.40	0.97
Intercrop MSh1R	0.38	-	-	0.38	0.78	1.16
Intercrop MSh3R	0.30	-	-	0.41	0.58	0.98

† Cropping pattern abbreviations: M=millet, Sf=*Stylosanthes fruticosa*, Sh=*S. hamata*, 1R=Alternate single-row planting arrangement, 3R=Alternate triple-row planting arrangement.

‡ Relative yield = Yield of intercrop / yield of monocrop.

LER = Sum of relative yield of intercrop components.

Table A.7. Nitrogen (N) and phosphorus (P) uptake of millet and stylo in planting strategy II.

1989						
Cropping pattern†	----- N -----			----- P -----		
	Grain	Stover	Stylo	Grain	Stover	Stylo
----- kg ha ⁻¹ -----						
Pure millet	14.8	24.3	--	1.9	3.5	--
Intercrop MSf1R	6.0	10.4	38.0	1.1	1.4	3.2
Intercrop MSh1R	6.5	10.5	89.8	1.0	1.1	6.9
Intercrop MSf3R	2.0	6.2	51.3	0.4	0.8	4.6
Intercrop MSh3R	2.4	8.0	88.7	0.5	1.3	5.5
<u>S. fruticosa</u>	--	--	64.2	--	--	5.1
<u>S. hamata</u>	--	--	24.4‡	--	--	1.7
LSD 0.05	4.1	6.2	16.9	0.6	0.9	1.5

1990						
Pure millet	15.0	15.1	--	2.2	1.5	--
Intercrop MSf1R	8.2	12.5	31.2	1.2	1.0	2.0
Intercrop MSh1R	4.9	8.0	58.0	0.8	1.1	3.3
Intercrop MSf3R	10.1	7.0	23.1	1.6	0.8	2.0
Intercrop MSh3R	6.7	9.4	43.3	1.2	1.0	2.9
<u>S. fruticosa</u>	--	--	56.4	--	--	4.6
<u>S. hamata</u>	--	--	80.9	--	--	5.3
LSD 0.05	3.0	5.7	9.6	0.4	NS	0.7

† Cropping pattern abbreviations: M=millet, Sf=Stylosanthes fruticosa, Sh=S. hamata, 1R=Alternate single-row planting arrangement, 3R=Alternate triple-row planting arrangement.

‡ Sh was harvested only once in 1989.

Table A.8. Probability levels (F-test) for cropping pattern (CR), year, and CR by year interaction effects on (1) water use (WU) and water use efficiency (WUE), and on (2) selected soil chemical properties at the experimental sites.

(1)

Source	WU	WUE [†]		
		DM	grain	stover
Cropping pattern (CR)	0.03	0.01	0.01	0.01
Year	0.01	0.01	0.01	0.01
CR X Year	0.64	0.01	0.01	0.44

(2)

Source	Responses [‡]				
	pH-KCl	pH-H ₂ O	P	OM	N
Site A					
Period	0.16	0.02	0.01	0.05	0.01
Cropping pattern (CR)	0.45	0.03	0.01	0.45	0.31
CR X period	0.06	0.02	0.80	0.62	0.86
Site B					
Period	0.01	0.01	0.10	0.40	0.04
Cropping pattern (CR)	0.22	0.51	0.01	0.24	0.47
CR X period	0.99	0.90	0.02	0.94	0.92

[†] WUE = Output (dry matter, grain, stover)/water use.

[‡] Soil response variables: OM=Organic matter, P=Phosphorous, N=Nitrogen.

Table A.9. Correlation coefficient among selected millet parameters following 1-yr (1989-1, 1990-1) and 2-yr (1990-2) previous millet/style cropping.

1989-1

	Grain	Stover	Total N	Total P
Grain		0.82	0.88	0.92
Stover			0.96	0.93
Total nitrogen				0.92
Total phosphorous				

1990-1

	Grain	Stover	Total N	Total P
Grain		0.57	0.48	0.73
Stover			0.77	0.76
Total nitrogen				0.62
Total phosphorous				

1990-2

	Grain	Stover	Total N	Total P
Grain		0.40	0.57	0.67
Stover			0.76	0.70
Total nitrogen				0.65
Total phosphorous				

Table A.10. Regression estimates of selected millet parameters over 1-yr (1989-1, 1990-1) and 2-yr (1990-2) previous millet/stylo cropping.

1989-1				
Response variables†	Regression coefficient			R ²
	b0	b1	b2	
Total N uptake	16.10	5.65	-	0.12
Grain N	2.01	0.13	-	0.15
Stem N	0.40	0.19	-	0.35
NUE	23.80	-2.95	-	0.20
N partition	0.50	-0.05	-	0.17
1990-1				
Total N uptake	29.20	9.60	-	0.32
Grain N	2.57	0.23	-	0.56
Stem N	0.11	0.24	-	0.56
NUE	33.70	-4.90	-	0.60
N partition	0.56	-0.05	-	0.31
1990-2				
N uptake	17.60	12.01	-	0.64
Grain N	1.26	0.27	-	0.62
Stover	2370.10	263.30	-	0.16
N partition	0.53	-0.02	-	0.03
Grain P	0.36	-0.06	0.01	0.09

† Response variables abbreviations: N=nitrogen, NUE=nitrogen use efficiency, P=phosphorous.

Table A.11. Regression estimates of millet leaf nitrogen (N) concentration response to fertilizer N as affected by 1-yr previous millet/stylo cropping.

1989			
Previous cropping pattern [†]	Regression coefficient		R ²
	b0	b1	
Pure millet	0.46	0.73	0.15
Intercrop MSf1R	0.94	0.12	0.36
Intercrop MSf3R	1.08	0.17	0.28
Intercrop MSh1R	0.84	0.17	0.61
Intercrop MSh3R	0.79	0.26	0.51
<u>S. fruticosa</u>	1.14	0.19	0.36
<u>S. hamata</u>	0.66	0.33	0.50
1990			
Pure millet	0.59	0.19	0.62
Intercrop MSf1R	0.80	0.12	0.53
Intercrop MSh1R	0.51	0.25	0.74
<u>S. fruticosa</u>	0.67	0.15	0.61
<u>S. hamata</u>	0.62	0.14	0.59

[†] Cropping pattern abbreviations: M=millet, Sf=Stylosanthes fruticosa, Sh=S. hamata, 1R=Alternate single-row planting arrangement, 3R=Alternate triple-row planting arrangement.

Table A.12. Regression estimates of millet leaf phosphorous concentration response to fertilizer N as affected by 1-yr previous millet/stylo cropping.

1989			
Previous cropping pattern†	Regression coefficient		R ²
	b0	b1	
Pure millet	0.21	-0.010	0.45
Intercrop MSf1R	0.12	0.005	0.11
Intercrop MSf3R	0.11	0.010	0.20
Intercrop MSh1R	0.11	0.020	0.52
Intercrop MSh3R	0.11	0.005	0.25
<u>S. fruticosa</u>	0.15	0.005	0.05
<u>S. hamata</u>	0.11	0.009	0.11

1990			
Pure millet	0.046	0.017	0.23
Intercrop MSf1R	0.068	0.010	0.18
Intercrop MSh1R	0.050	0.018	0.57
<u>S. fruticosa</u>	0.054	0.016	0.33
<u>S. hamata</u>	0.089	0.070	0.22

† Cropping pattern abbreviations: M=millet, Sf=Stylosanthes fruticosa, Sh=S. hamata, 1R=Alternate single-row planting arrangement, 3R=Alternate triple-row planting arrangement.

Table A.13. Regression estimate of millet grain yield and nitrogen use efficiency (NUE) response to fertilizer N as affected by 2-yr previous millet/stylo cropping.

Grain			
Previous cropping pattern [†]	Regression coefficient		R ²
	b0	b1	
Pure millet	780.4	99.7	0.12
Intercrop MSf1R	974.8	103.2	0.07
Intercrop MSh1R	692.0	175.4	0.37
Intercrop MSf3R	1047.6	114.3	0.20
Intercrop MSh3R	1136.7	13.6	0.01
<u>S. fruticosa</u>	797.8	186.5	0.26
<u>S. hamata</u>	959.1	-12.4	0.01

NUE			
Pure millet	40.1	-6.1	0.59
Intercrop MSf1R	41.6	-5.2	0.45
Intercrop MSh1R	40.6	-5.1	0.36
Intercrop MSf3R	37.0	-4.1	0.62
Intercrop MSh3R	34.5	-4.2	0.29
<u>S. fruticosa</u>	41.6	-5.5	0.62
<u>S. hamata</u>	30.9	-3.9	0.35

[†] Cropping pattern abbreviations: M=millet, Sf=Stylosanthes fruticosa, Sh=S. hamata, 1R=Alternate single-row planting arrangement, 3R=Alternate triple-row planting arrangement.

Table A.14. Regression estimate of millet leaf and stem nitrogen (N) concentration response to N as affected by 2-yr previous millet/style cropping.

Leaf N			
Previous cropping pattern [†]	Regression coefficient		
	b0	b1	R ²
Pure millet	0.66	0.19	0.52
Intercrop MSf1R	0.54	0.20	0.73
Intercrop MSh1R	0.59	0.17	0.60
Intercrop MSf3R	0.74	0.18	0.76
Intercrop MSh3R	0.62	0.23	0.66
<u>S. fruticosa</u>	0.59	0.17	0.66
<u>S. hamata</u>	0.71	0.21	0.76

Stem N			
Pure millet	0.16	0.16	0.53
Intercrop MSf1R	0.15	0.12	0.68
Intercrop MSh1R	0.25	0.08	0.48
Intercrop MSf3R	0.21	0.11	0.72
Intercrop MSh3R	0.21	0.14	0.60
<u>S. fruticosa</u>	0.11	0.15	0.67
<u>S. hamata</u>	0.17	0.17	0.82

[†] Cropping pattern abbreviations: M=millet, Sf=Stylosanthes fruticosa, Sh=S. hamata, 1R=Alternate single-row planting arrangement, 3R=Alternate triple-row planting arrangement.

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BIOGRAPHICAL SKETCH

Christophe N. Kouamé was born on November 19, 1960, at Tiassalé in the Republic of Côte d'Ivoire. He went to elementary school in his hometown, M'bribo. He attended secondary and high school at Abidjan where he graduated in July 1980 with the degree 'Baccalaureat-D'.

Christophe entered the National University of Côte d'Ivoire, 'Faculté des Sciences', in October 1980. He earned the 'Diplôme Universitaire d'études Scientifiques' in June 1982. In October 1982, he enrolled at the 'Ecole Nationale Supérieure Agronomique' (ENSA) and received the 'Diplôme d'Agronomie Générale' in July 1984. From July to December 1984, he worked as research fellow at ENSA.

Christophe came to the University of Florida (UF) in January 1985. He attended the English Language Institute until May 1985, then, he completed a Master of Sciences (MS) program in Agronomy in August 1987. Upon being granted the MS degree at UF, Christophe was awarded the 'Diplôme d'Ingénieur Agronome' at ENSA and took up a position at the 'Institut des Savanes' of Bouaké, Côte d'Ivoire.

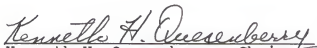
In June 1988, Christophe returned to the UF to continue graduate studies in Agronomy. He was a graduate Research Associate at the International Livestock Centre for Africa from May 1989 to May 1991. Presently, he is a candidate for

the degree of Doctor of Philosophy in the Department of Agronomy, University of Florida.

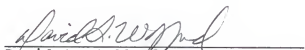
Christophe is member of the American Society of Agronomy, the Crop Science Society of America, the Florida Academy of Science, and the honorary society Gamma Sigma Delta.

Christophe is married to the former Marie Chantal Dadié. They have one daughter, Cristelle Ahunvin-kan.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.


Kenneth H. Quesenberry, Chairman
Professor of Agronomy

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David S. Wofford
Assistant Professor of Agronomy

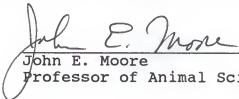
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This dissertation was submitted to the graduate faculty of the College of Agriculture and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

December 1991



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